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Draft Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

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List of Acronyms

ABT	Averaging, Banking, and Trading
AEO	Annual Energy Outlook
AGME	Above-ground mining equipment
AT	Aftertreatment
BSFC	Brake Specific Fuel Consumption
CCV	Closed crankcase ventilation
CDPF	Catalyzed diesel particulate filter
CFR	Code of Federal Regulations
CI	Compression-Ignition
CMV	Commercial Marine Vessel
CO	Carbon monoxide
DF	Deterioration Factor
DI	direct injection
DOC	Diesel oxidation catalyst
EF	Emission Factor
EGR	Exhaust gas recirculation
EIA	U. S. Energy Information Administration
EIA	Economic Impact Analysis
FR	Federal Register
FTC	Federal Trade Commission
GDP	Gross domestic product
HC	Hydrocarbons
HD2007	Heavy-duty 2007 refers to the final rule setting emission standards for 2007 and later engines used in heavy-duty highway vehicles.
hp	Horsepower
IDI	Indirect injection
IRFA	Initial Regulatory Flexibility Analysis
kW	kilowatt
L&M	Locomotive and marine
MPP	marginal physical product

NDEIM	Nonroad Diesel Economic Impact Model
NMHC	Non-methane hydrocarbons
NPV	Net present value
NR	Nonroad
NRLM	Nonroad, Locomotive, and Marine diesel fuel
O&M	operating and maintenance
OMB	Office of Management and Budget
PM	Particulate matter
ppm	Parts per million
PSR	Power Systems Research
RIA	Regulatory Impact Analysis
SBA	Small Business Administration
SBAR	Small Business Advocacy Review
SBREFA	Small Business Regulatory Enforcement Fairness Act
SER	Small Entity Representative
SIC	Standard Industrial Classification
stds	standards
TAF	Transient Adjustment Factor
TPEM	Transition program for engine manufacturers (see 40 CFR 89.102 and the proposed 40 CFR 1039.625)
VMP	value of marginal product
VOC	Volatile organic compounds
ZHL	Zero-Hour Emission Level

Executive Summary

The Environmental Protection Agency (EPA) is proposing requirements to reduce emissions of particulate matter (PM) and oxides of nitrogen (NOx) from nonroad diesel engines. This proposal includes emission standards for new nonroad diesel engines. The proposal also addresses the quality of the fuel used in nonroad engines, as well as locomotive and marine engines, by specifying reduced sulfur levels.

This executive summary first highlights the proposed emission standards and fuel requirements, then gives an overview of the analyses in the rest of this document.

Emission Standards and Engine Technologies

Tables 1 and 2 show the Tier 4 emission standards and when they apply. For most engines, these standards are similar in stringency to the final standards included in the 2007 highway diesel program and are expected to require the use of high-efficiency aftertreatment systems to ensure compliance. As shown in the table, we are phasing in many of the proposed standards over a two- or three-year period to address lead time, workload, and feasibility considerations.

Table 1
Proposed PM Standards (g/bhp-hr) and Schedule

Engine Power	Model Year					
	2008	2009	2010	2011	2012	2013
hp < 25 (kW < 19)	0.30					
25 ≤ hp < 75 (19 ≤ kW < 56)	0.22					0.02
75 ≤ hp < 175 (56 ≤ kW < 130)					0.01	
175 ≤ hp ≤ 750 (130 ≤ kW ≤ 560)				0.01		
hp > 750 (kW > 560)				0.01		

Table 2
Proposed NOx and NMHC Standards and Schedule

Engine Power	Standard (g/bhp-hr)	
	NOx	NMHC
25 ≤ hp < 75 (19 ≤ kW < 56)	3.5 NMHC+NOx	
75 ≤ hp < 175 (56 ≤ kW < 130)	0.30	0.14
175 ≤ hp ≤ 750 (130 ≤ kW ≤ 560)	0.30	0.14
hp > 750 (kW > 560)	0.30	0.14

	Phase-in Schedule			
	2011	2012	2013	2014
25 ≤ hp < 75 (19 ≤ kW < 56)			100%	
75 ≤ hp < 175 (56 ≤ kW < 130)		50%	50%	100%
175 ≤ hp ≤ 750 (130 ≤ kW ≤ 560)	50%	50%	50%	100%
hp > 750 (kW > 560)	50%	50%	50%	100%

The proposal includes new provisions to help ensure that emission-control systems perform as well when operating in actual service conditions as in the laboratory. These procedures will also allow for testing an engine's emission levels while the machinery operates in normal service.

Controls on In-use Diesel Fuel

Just as lead was phased out of gasoline because it damages catalytic converters in cars, sulfur can contaminate high-efficiency emission-control systems used on diesel engines. Nonroad diesel fuel currently has sulfur levels up to 3,400 parts per million (ppm). This proposal would reduce these levels by 99 percent, which is an essential step in achieving the emission reductions anticipated under the proposal.

Starting in 2007, fuel sulfur levels in nonroad diesel fuel would be limited to a maximum of 500 ppm, the same as for current highway diesel fuel. This limit also covers fuels used in locomotive and marine applications (though not to the marine residual fuel used by very large engines on ocean-going vessels). Reducing fuel sulfur levels to 500 ppm or lower will provide immediate public health benefits by reducing particulate emissions from engines in the existing fleet of nonroad equipment, with the added benefit of reducing the cost of maintaining engines.

The proposal includes a second step of fuel controls to a 15-ppm limit on sulfur content that would apply in 2010. This additional reduction in sulfur levels will further reduce PM emissions from existing engines. More importantly, the ultra-low sulfur levels will make it possible for engine manufacturers to use advanced emission-control systems that will achieve dramatic reductions in both PM and NOx emissions. In addition, we are seriously considering whether to establish new emissions standards in the future that would reduce the emissions from locomotive and marine engines by more than 90 percent with the same advanced emission-control technologies included in this proposal.

Estimated Costs of the Proposal

There are approximately 600 nonroad equipment manufacturers using diesel engines in several thousand different equipment models. Fixed costs consider engine research and development, engine tooling, engine certification, and equipment redesign. Variable costs include estimates for new emission-control hardware. Near-term and long-term costs for some example pieces of equipment are shown in Table 3. Also shown in Table 3 are typical prices for each piece of equipment for reference. See Chapter 6 for additional detailed information related to cost analyses related to engines and equipment.

Table 3
Long-Term Costs for Several Example Pieces of Equipment[a]

	GenSet	Skid/Steer Loader	Backhoe	Dozer	Agricultural Tractor	Dozer	Off-Highway Truck
Horsepower	9 hp	33 hp	76 hp	175 hp	250 hp	503 hp	1000 hp
Displacement (L)	0.4	1.5	3.9	10.5	7.6	18	28
Incremental Engine & Equipment Cost							
Long Term	$120	$760	$1,210	$2,590	$2,000	$4,210	$6,780
Near Term	$170	$1,100	$1,680	$3,710	$2,950	$6,120	$10,100
Estimated Equipment Price[b]	$3,500	$13,500	$50,000	$235,000	$130,000	$575,000	$700,000

[a] Near-term costs include both variable costs and fixed costs; long-term costs include only variable costs and represent those costs that remain following recovery of all fixed costs.

Our estimated costs related to upgrading to low-sulfur fuel takes into account all the necessary changes in both refining and distribution practices. We have estimated the cost of producing 500-ppm fuel to be on average 2.5 cents per gallon. Average costs for 15-ppm fuel are estimated to be an additional 2.3 cents per gallon for a combined cost of 4.8 cents per gallon, as shown in Table 4. These ranges consider variations in regional issues in addition to factors that are specific to individual refiners. In addition, engines running on low-sulfur fuel will have reduced maintenance expenses that we estimate will be equivalent to reducing the cost of the fuel by 3.3 cents per gallon.

Table 4
Increased Cost of Providing Nonroad,
Locomotive and Marine Diesel Fuel (cents per gallon of affected fuel)

	Refining	Distribution	Total
Step One - 500 ppm NRLM diesel fuel	2.2	0.3	2.5
Step Two - 15 ppm Nonroad diesel fuel	4.4	0.4	4.8
Step Two - 500 ppm Locomotive and Marine diesel fuel	2.2	0.2	2.4

Cost per Ton of Reduced Emissions

Chapter 8 describes the analysis of aggregating the incremental fuel costs, operating costs, and the costs for producing compliant engines and equipment, operating costs. Table 5 compares these aggregate costs with the corresponding estimated emission reductions to present cost-per-ton figures for the various pollutants.

Table 5
Aggregate Cost per Ton for the Proposed Two-Step Fuel Program
and Engine Program—2004-2036 Net Present Values at 3% Discount Rate ($2001)

Pollutant	Aggregate Discounted Lifetime Cost per ton
NOx+NMHC	$810
PM	$8,700
SO_x	$200

Estimated Emission Reductions, Air Quality Impacts and Benefits

Based on our most recent nationwide inventory used for this proposal (1996), we estimate that the nonroad diesel engines affected by this proposal contribute about 44 percent of diesel PM emissions and 12 percent of NOx emissions from mobile sources. By 2020, these engines will emit over 60 percent of diesel PM and 20 percent of NOx from mobile sources. When fully implemented, this proposal would reduce PM and NOx emissions from nonroad diesel engines by more than 90 percent. It will also virtually eliminate emissions of sulfur oxides (SOx) from these engines, which amounted to nearly 300,000 tons in 1996, and would otherwise grow to approximately 380,000 tons by 2020. These dramatic emission reductions emissions are a critical part of the effort by federal, state, local, and tribal governments to reduce the health-related impacts of air pollution.

Reducing NOx and PM emissions from nonroad diesel engines by more than 90 percent would provide a wide range of benefits for public health and the environment. We have estimated that, by 2030, controlling these emissions would annually prevent 9,600 premature deaths, over 8,300 hospitalizations, and almost a million work days lost. All told, the monetized health benefits of this rule would be $81 billion annually once the program is fully phased in. Costs for both the engine and fuel requirements would be significantly less, at approximately $1.5 billion annually. See the fact sheet referenced below for further description of these environmental benefits.

Economic Impact Analysis

An Economic Impact Analysis was prepared for this proposal to estimate its potential economic impacts on producers and consumers of nonroad engines and equipment and fuels, and related industries. The Economic Impact Analysis has two parts: a market analysis and a welfare analysis. The market analysis explores the impacts of the proposed program on prices and quantities of affected products. The welfare analysis focuses on changes in social welfare and explores which entities will bear the burden of the proposed program. A multi-market partial equilibrium approach was used to track changes in price and quantity for 60 integrated product markets. The model and data inputs are described in Chapter 10.

As shown in Table 6, the market analysis predicts that the overall economic impact of the proposed emission control program on society is expected to be small, on average. According to this analysis, the average prices of goods and services produced using equipment and fuel affected by the proposal (the application markets) are expected to increase about 0.02 percent. Engine prices are expected to increase, on average, about 22.9 percent in 2013, decreasing to about 19.5 percent for 2020 and after. The average price increase for nonroad equipment is expected to be about 5.2 percent in 2013, decreasing to 4.4 percent by 2020. The average price increase for nonroad diesel fuel for all years is expected to be about 4.1 percent. Quantities of products affected by this proposal are expected to decline negligibly, by less that 0.02 percent.

Table 6
Summary of Expected Market Impacts, 2013 and 2020

Market	2013			2020		
	Average engineering cost per unit	Price change	Quantity change	Average engineering cost per unit	Price change	Quantity change
Engines	$1,087	22.9%	-0.013%	$1,028	19.5%	-0.013%
Equipment	$1,021	5.2%	-0.014%	$1,018	4.4%	-0.014%
Application markets[a]	—	0.02%	-0.010%	—	0.02%	-0.010%
Nonroad Fuel Markets	$0.039	4.1%	-0.013%	$0.039	4.1%	-0.014%

[a] Commodities in the application markets are normalized; only percentage changes are presented

The welfare analysis predicts that consumers and producers in the application markets are expected to bear the burden of this proposed program. In 2013, the total social costs of the rule are estimated to be about $1,202 million. About 82 percent of the total social costs are expected to be borne by producers and consumers in the application markets, indicating a majority of the costs are expected to be passed on in the form of higher prices. When these estimated impacts are broken down, 58 percent are expected to be borne by consumers in the application markets and 42 percent are expected to be borne by producers in the application markets. Equipment manufacturers are expected to bear about 10 percent of the total social costs. These are primarily the costs associated with equipment redesign. Engine manufacturers are expected to bear about 2.5 percent; this is primarily the fixed costs for R&D. Nonroad fuel refiners are expected to bear about 0.5 percent of the total social costs. The remaining 5 percent is accounted for by fuel marker costs and the additional costs of 15 ppm fuel being sold in to markets such as marine diesel, locomotive, and home heating fuel that do not require it.

In 2020, the social costs of the rule are expected to increase to about $1,510 million. Producers and consumers in the applications markets are expected to bear nearly all of these costs, about 94 percent. This is consistent with economic theory, which states that, in the long run, all costs are passed on to the consumers of goods and services.

Alternative program options

In the course of designing our proposed program, we investigated several alternative approaches to both the engine and fuel programs. These alternative program options included variations in:

- The applicability of aftertreatment-based standards for different horsepower categories
- The phase-in schedule for engine standards
- The start date for the diesel fuel sulfur standard
- The use of a single-step instead of a two-step approach to fuel sulfur standards
- The applicability of the very-low fuel sulfur standards to fuel used by locomotives and marine engines

Chapter 12 includes a complete evaluation of twelve alternative program options, including an assessment of technical feasibility, cost, cost-effectiveness, inventory impact, and health and welfare benefits for each alternative. Table 12.6.1-1 summarizes the alternative program options, while the accompanying text in Section 12.6 presents our rationale for choosing the proposed program rather than one of the alternatives.

CHAPTER 1: Industry Characterization

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CHAPTER 1: Industry Characterization

In understanding the impact of emissions standards on regulated industries, it is important to assess the nature of the regulated and otherwise affected industries. The industries affected are the nonroad diesel engine and equipment manufacturing, oil-refining, and fuel-distribution industries. This chapter provides market share information for the above industries. This information is provided for background purposes. In the remainder of this draft RIA, to the extent data regarding engine/equipment populations, sales or other industry specific data has been used, that data is explained and referenced in the relevant section of the draft RIA. The information presented in this chapter will be most helpful for the reader who is unfamiliar with the engine/equipment industry and/or the oil refining and fuel-distribution industries.

Nonroad engines are generally distinguished from highway engines in one of four ways: (1) the engine is used in a piece of motive equipment that propels itself in addition to performing an auxiliary function (such as a bulldozer grading a construction site); (2) the engine is used in a piece of equipment that is intended to be propelled as it performs its function (such as a lawnmower); (3) the engine is used in a piece of equipment that is stationary when in operation but portable (such as a generator or compressor) or (4) the engine is used in a piece of motive equipment that propels itself, but is primarily used for off-road functions (such as off-highway truck).

The nonroad category is also different from other mobile source categories because: (1) it applies to a wider range of engine sizes and power ratings; (2) the pieces of equipment in which the engines are used are extremely diverse; and (3) the same engine can be used in widely varying equipment applications (e.g., the same engine used in a backhoe can also be used in a drill rig or in an air compressor).

A major consideration in regulating nonroad engines is the lack of vertical integration in this field. Although some nonroad engine manufacturers also produce equipment that rely on their own engines, most engines are sold to various equipment manufacturers over which the original engine manufacturer has minimal control. A characterization of the industry affected by this rulemaking must therefore include equipment manufacturers as well as engine manufacturers.

Sections 1 and 2 characterize the nonroad engine and equipment industries based on different manufacturers and their products and the diversity of the manufacturer pool for the various types of equipment. They describe the nonroad diesel engine market and related equipment markets by horsepower category. Additional information related to engine/equipment profiles, including employment figures, production costs, information on engine component materials and firm characteristics, are available in the docket.[1]

1.1 Characterization of Engine Manufacturers

For purposes of discussion, the characterization of nonroad engine manufacturers is arranged by the power categories used to define the new emission standards. The information detailed in this section was derived from the Power Systems Research database and trade journals.[2] We recognize that the PSR database is not comprehensive, but have not identified a better source to provide consistent data for identifying additional companies.

1.1.1 Engines Rated between 0-19 kW (0 and 25 hp)

In year 2000, sales of engines in this category comprised 18% (approximately 135,828 units) of the nonroad market. The largest manufacturers of engines in this category are Kubota (36,601 units) and Yanmar (32,126 units). Seventy three percent of Yanmar's engines are four-cycle, water-cooled, indirect injection models. A majority of Kubota's engines are also four-cycle, water-cooled indirect injection models. Another major manufacturer in this category is Kukje with 21,216 units.

1.1.2 Engines Rated between 19 and 56 kW (25 and 75 hp)

This is the largest category, comprised of 38% of engines with approximately 281,157 units sold in year 2000. Direct Injection (DI) engines account for 59% of this category with 165,427 units. Yanmar has approximately 19% of the DI market share, followed by Deutz (16%), Kubota (13%), Hatz (12%), Isuzu(10%) ,Caterpillar/Perkins(10%) and Deere (8%). Kubota dominates the Indirect Injection (IDI) market with 51 percent of sales , followed by Daewoo Heavy Industries (12%), Ihi-Shibaura (12%), Isuzu(8%) and Caterpillar/Perkins (5%). Ag tractors, generator sets, skid-steer loaders and refrigeration and air conditioning units are the largest selling engines in this power range.

1.1.3 Engines Rated between 56 and 130 kW (75 and 175 hp)

In year 2000, manufacturers sold approximately 206,028 engines in this power range. This represents the second-largest category of nonroad engines with 28% of the total market. Almost all of these engines are DI. The top three manufacturers are John Deere (28%), Caterpillar/Perkins (20%) and Cummins (17%). Other manufacturers include Case/ New Holland, Deutz, Hyundai Motor, Isuzu, Toyota and Komatsu. The engines in this power range are used mostly in agricultural equipment such as ag tractors. The second-largest use for these engines is in construction equipment such as tractor/loader/backhoes and skid-steer loaders.

1.1.4 Engines Rated between 130 and 560 kW (175 and 750 hp)

Engines in this power range rank fourth(15% of the total market) in nonroad diesel engines sales with approximately 108,172 units sold in year 2000. Almost all of these are DI engines. Deere has approximately 32% of the DI market, followed by Caterpillar/Perkins (22%), Cummins (21%), Case/New Holland (8%),Volvo (4%), and then by Komatsu and Detroit Diesel (each 3%). The largest selling engines in this category are used in agricultural equipment (ag tractors), followed by construction equipment (wheel loaders, bulldozers, and excavators).

1.1.5 Engines Rated over 560 kW (750 hp)

This is the smallest nonroad category with approximately 5,633 engines comprising 1% of the total nonroad market and consist of all DI engines. Caterpillar is the largest manufacturer (44%), followed by Cummins (19%), Komatsu (18%), and Detroit Diesel (11%). Power generation is the principal application in this range, followed by large off-highway trucks and other types of construction equipment such as crawlers , wheel loaders and bulldozers.

1.2 Characterization of Equipment Manufacturers

Nonroad equipment can be grouped into several categories. This section considers the following seven segments: agriculture, construction, general industrial, lawn and garden, material handling, pumps and compressors, and welders and generator sets. Engines used in locomotives, marine applications, aircraft, recreational vehicles, underground mining equipment, and all spark-ignition engines within the above categories are not included in this proposed rulemaking. Table 1.2-1 below contains examples of the types of nonroad equipment which would be impacted by this proposal, arranged by category.

Table 1.2-1
Sampling of Nonroad Equipment Applications

Segment	Applications		
Agriculture	Ag Tractor Baler Combine	Sprayer Windrower Other Ag Equipment	
Construction	Bore/drill Rig Crawler Excavator Grader Off-highway Tractor	Off-highway Truck Paver Plate Compactor Roller Wheel Loader/Dozer	Tamper/Rammer Scraper Skid-Steer Loader Trencher
General Industrial	Concrete/Ind. Saw Crushing Equipment	Oil Field Equipment Refrigeration/AC	Scrubber/sweeper Rail Maintenance
Lawn and Garden	Lawn and Garden Tractor	Commercial Mower	Trimmer/edger/cutter
Pumps and Compressors	Air Compressor Hydro Power Unit Pressure Washer	Pump Gas Compressor	Irrigation Set
Material Handling	Aerial Lift Crane	Forklift Terminal Tractor	Rough-Terrain Forklift
Welders and Generators	Generator Set, Welder	Lt Plant/Signal Board	

Based on horsepower rating of the engine it uses, a fraction of applications such as air compressors, generator sets, hydropower units, irrigation sets, pumps and welders is considered to be stationary and hence not subject to EPA's proposed.standards. However, the tables in sections 1.2.1 to 1.2.5 account for all equipment manufactured, whether stationary or mobile within an engine horsepower category.

For purposes of discussion, nonroad equipment is grouped into five power ranges similar to those used for characterizing nonroad engines. This section explores the characteristics of nonroad equipment applications and the companies involved in manufacturing these equipment. This analysis includes several numerical summaries of different categories.

1.2.1 Equipment Using Engines Rated under 19 kW (0 and 25 hp)

The applications with the most sales are ag tractors followed by generator sets. There are about 29 total applications with engines rated under 19 kW. The six leading manufacturers produce 46% of the equipment in this category. Their collective sales volume over five years (1996 to 2000) was approximately 251,000 pieces of equipment in a market which has a five year total sales volume of 551,000. These manufacturers and the major equipment types manufactured by them are shown in Table 1.2-2.

Table 1.2-2
Characterization of the Top 6 Equipment Manufacturers for Engines Rated below 19 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Average Annual Sales	Percentage of Market	Engine Characterization*
Ingersoll-Rand	Refrigeration/AC, Skid-steer loaders, and Excavators	13,394	12%	W,NA, I
Deere & Company	Agricultural tractors, Commercial mowers, Lawn & garden tractors	11,042	10%	W,NA, I
Korean Gen-sets	Generator Sets	9,970	9%	W,NA, I
China Gen-sets	Generator Sets	5,559	5%	W,NA,D/ I
SDMO	Generator Sets	5,191	5%	W/A,NA, D/I
Kubota Corp.	Ag tractors,Lawn & garden tractors Commercial mowers	5,117	5%	W,NA,I

*W=water-cooled, A=air-cooled,O=oil cooled;NA=naturally aspirated,T=turbocharged;I=indirect injection,D=direct injection.

For these top six OEMs, their sales are typified by generator sets, skid-steer loaders, ag tractors, commercial mowers, and refrigeration/air conditioning units. The sales of the equipment are listed in Table 1.2-3. The top six manufacturers have equipment that are typical of the market. Fifty-six OEMs produce 92% of the equipment in this horsepower range.

Table 1.2-3
Equipment Sales Distribution for Engines Rated below 19 kW

Application Description	Five-year sales Volume (1996-2000)	Average Annual Sales	Percentage of Total Sales
Generator sets	171,435	34,287	31.1
Agricultural tractors	59,863	11,973	9.5
Commercial mowers	59,713	11,943	9.5
Refrigeration/AC	57,668	11,534	9.2
Welders	32,284	6,457	5.1
Light plants/Signal boards	28,239	5,648	4.5
Skid-steer loaders	23,685	4,737	3.8
Lawn & garden tractors	17,879	3,576	2.8
Pumps	16,262	3,252	2.6
Rollers	12,063	2,413	1.9
Pressure washers	11,959	2,392	1.9
Plate compactors	11,535	2,307	1.8
Utility vehicles	8,502	1,700	1.4
Aerial lifts	7,058	1,412	1.1
Excavators	6,118	1,224	1.0
Mixers	4,639	928	0.7
Scrubbers/sweepers	2,829	566	0.4
Commercial turf equipment	2,627	525	0.4
Finishing equipment	2,351	470	0.4
Other general industrial equipment	2,334	467	0.4
Tampers/rammers	2,156	431	0.3
Tractor/loader/backhoes	1,794	359	0.3
Dumpers/tenders	1,689	338	0.3
Air compressors	1,516	303	0.2
Hydraulic power units	797	159	0.1
Trenchers	776	155	0.1
Concrete/industrial saws	733	147	0.1
Irrigation sets	614	123	0.1
Wheel loaders/bulldozers	502	100	0.1
Other agricultural equipment	426	85	0.1
Surfacing equipment	362	72	0.1
Bore/drill rigs	275	55	0.0
Listed Total		110,137	91.4
Grand Total		**110,289**	**100.0**

1.2.2 Equipment Using Engines Rated between 19 and 56 kW (25 and 75 hp)

All market segments are represented within the 19 to 56 kW range. They are made up of 55 applications and about 17 % of total sales are by Ingersoll- Rand. For the 19 to 56 kW range, the equipments use either direct or indirect injection engines that are water or oil-cooled and are either naturally aspirated or turbo-charged. The six leading manufacturers produce 53% of the equipment in this category. These manufacturers are listed in Table 1.2-4. They manufacture equipment typical of the market e.g. agricultural tractors, generator sets, skid-steer loaders and refrigeration/AC. These top selling applications represent about 70% of the market as seen in Table 1.2-5. The top 90% of the market is supplied by 60 different companies.

Table 1.2-4
Characterization of the Top 6 Equipment
Manufacturers for Engines Rated between 19 and 56 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Average Annual Sales	Percentage of Market	Engine Characterization*
Ingersoll-Rand	Refrigeration A/C, Skid-steer loaders, Air compressors	40,199	17%	W/O,NA/T,D/I
Case New Holland	Agricultural tractors, Skid-steer loaders	23,194	10%	W/O,NA/T,D/I
Thermadyne Holdings	Generator sets	19,090	8%	A,NA,D
Deere & Company	Agricultural tractors, Skid-steer loaders, Commercial mowers	17,752	7%	W,NA/T,D
Kubota Corp.	Agricultural tractors, Excavators, Wheel Loaders, Bulldozers	14,391	6%	W,NA/T,D/I
United Technologies Co.	Refrigeration/AC	12,484	5%	W,NA,D/I

*W=water-cooled, A=air-cooled,O=oil cooled;NA=naturally aspirated, T=turbocharged, I=indirect injection, D=direct injection.

Table 1.2-5
Equipment Sales Distribution across Applications between 19 and 56 kW

Application Description	Five-year sales Volume (1996-2000)	Average Annual Sales	Percentage of Total Sales
Agricultural tractors	286,295	57,259	24%
Generator sets	223,960	44,792	19%
Skid-steer loaders	177,925	35,585	15%
Refrigeration/AC	142,865	28,573	12%
Welders	60,035	12,007	5.0%
Commercial mowers	47,735	9,547	3.9%
Air compressors	33,840	6,768	2.8%
Trenchers	26,465	5,293	2.2%
Aerial lifts	25,810	5,162	2.1%
Forklifts	23,480	4,696	1.9%
Rollers	18,010	3,602	1.5%
Excavators	16,485	3,297	1.4%
Rough terrain forklifts	13,530	2,706	1.1%
Scrubbers/sweepers	11,770	2,354	1.0%
Light plants/signal boards	11,720	2,344	1.00%
Pumps	9,290	1,858	0.77%
Bore/drill rigs	9,000	1,800	0.74%
Utility vehicles	8,460	1,692	0.70%
Wheel Loaders/bulldozers	6,985	1,397	0.58%
Pressure washers	6,700	1,340	0.55%
Pavers	6,395	1,279	0.53%
Commercial turf	5,760	1,152	0.48%
Tractor/loader/backhoes	5,115	1,023	0.42%
Irrigation sets	4,300	860	0.36%
Concrete/industrial saws	3,400	680	0.28%
Other general industrial	3,400	680	0.28%
Chippers/grinders	2,625	525	0.22%
Crushing/processing equipment	2,305	461	0.19%
Hydraulic power units	1,950	390	0.16%
Terminal tractors	1,765	353	0.15%
Surfacing equipment	1,490	298	0.12%
Dumpers/tenders	1,055	211	0.09%
Listed Total		239,984	99.3%
Grand Total		241,710	100.0%

1.2.3 Equipment Using Engines Rated between 56kW and 130 kW (75 and 175 hp)

Engines rated between 56 and 130 kW are all direct injection engines that are either water-cooled (94%), oil-cooled (4%) or air-cooled (2%). The six leading manufacturers produce 49% of the equipment in this category. Their collective sales volume over five years (1996 to 2000) was approximately 440,000 pieces of equipment in a market which has a five year total sales volume of 905,000. These manufacturers are shown in Table 1.2-6.

Table 1.2-6
Characterization of the Top 6 Equipment
Manufacturers for Engines Rated between 56kW and 130 kW (75 and 175 hp)

Original Equipment Manufacturer	Major Equipment Manufactured	Average Annual Sales	Percentage of Market	Engine Characterization*
Case New Holland	Ag Tractors, Combines, Crawlers, Skid-steer loaders, Tractors/loaders/backhoes	26,717	15%	W,T,D
Deere & Company	Ag Tractors, Combines, Wheel Loaders/Dozers	25,648	14%	W,T,D
Caterpillar	Generator Sets, Scrapers, Crawlers, Excavators, Wheel loaders, bulldozers, Graders, Rough terrain fork-lifts	13,670	8%	W,T/N,D
Ingersoll-Rand	Air compressors, Rollers, Bore/drill rigs	10,169	6%	W,T,D
Agco	Agricultural tractors, Combines, Sprayers	6,182	3%	W/A,T,D
Landini Holding	Agricultural tractors	5,467	3%	W,T/N,D

*W=water-cooled, A=air-cooled,O=oil cooled;NA=naturally aspirated, T=turbocharged, I=indirect injection, D=direct injection.

Of these top six OEMs, their sales are typified by agricultural tractors, tractors/loaders/backhoes, generator sets, skid-steer loaders, rough terrain fork-lifts,excavators, air compressors and crawlers. The sales of these equipment are listed in Table 1.2-7. The top six manufacturers have engines that are typical of the market. Seventy-two OEMs produce 90% of the equipment in this horsepower range.

Table 1.2-7
Equipment Sales Distribution across Applications between 56 and 130 kW

Application Description	Five-yr sales Volume (1996-2000)	Average Annual Sales	Percentage of Total Sales
Agricultural tractors	185,315	37,063	20%
Tractor/loader/backhoes	106,780	21,356	12%
Generator sets	103,490	20,698	11%
Skid-steer loaders	74,040	14,808	8.2%
Rough terrain forklfts	56,770	11,354	6.3%
Excavators	50,140	10,028	5.5%
Air compressors	32,080	6,416	3.5%
Crawlers	30,260	6,052	3.3%
Forklifts	29,705	5,941	3.3%
Wheel Loaders/bulldozers	27,520	5,504	3.0%
Rollers	23,195	4,639	2.6%
Commercial turf equipment	17,425	3,485	1.9%
Other general industrial	16,580	3,316	1.8%
Scrubbers/sweepers	16,005	3,201	1.8%
Irrigation sets	15,745	3,149	1.7%
Windrowers	11,385	2,277	1.3%
Pumps	10,265	2,053	1.1%
Sprayers	8,830	1,766	1.0%
Listed Total		163,108	90.1%
Grand Total		181,094	100.0%

1.2.4 Equipment Using Engines Rated between 130 and 560 kW (175 and 750 hp)

For the 130 to 560 kW range (where 560 kW is included in the range), most of the equipment uses direct injection engines that are water-cooled and turbo charged . A few are naturally aspirated. The six leading manufacturers produce 56% of the equipment in this category. These manufacturers are listed in Table 1.2-8. Their products have the following applications : ag tractors, combines, generator sets, wheel loaders/bull dozers , which is typical of the market.

The 130 to 560 kW range is characterized by applications as shown in Table 1.2-9. They represent about 94% of the market. The top 90% of this market is supplied by 60 OEMs.

Table 1.2-8
Characterization of the Top 6 Equipment Manufacturers
for Engines Rated between 130 and 560 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Average Annual Sales	Percentage of Market	Engine Characterization*
Deere & Company	Ag Tractors, Combines, Wheel Loaders/bulldozers	27,990	27%	W,T,D
Case New Holland	Ag Tractors, Combines, Crawlers, Generator Sets, Scrapers, Crawlers,	14,778	14%	W,T,D
Caterpillar	Excavators,wheel loaders/dozers, graders	13,151	13%	W,T/N,D
Komatsu	Crawlers, Excavators,Graders, Wheel Loaders/Dozers	4,941	5%	W,T,D
Ingersoll-Rand	Air Compressors, Rollers, Bore/Drill Rigs	3,683	4%	W,T,D
Agco	Ag Tractors, Combines, Sprayers	3,194	3%	W/A,T,D

*W=water-cooled, A=air-cooled,O=oil cooled;NA=naturally aspirated, T=turbocharged, I=indirect injection, D=direct injection.

Table 1.2-9
Equipment Sales Distribution across Applications between 130 and 560 kW

Application Description	Five-yr sales Volume (1996-2000)	Average Annual Sales	Percentage of Total Sales
Agricultural tractors	149,589	29,918	29.0%
Generator sets	57,400	11,480	11.0%
Wheel loaders/bulldozers	43,475	8,695	8.3%
Combines	35,743	7,149	6.8%
Excavators	35,166	7,033	6.7%
Crawlers	28,478	5,696	5.4%
Air compressors	20,884	4,177	4.0%
Graders	14,814	2,963	2.8%
Sprayers	12,193	2,439	2.3%
Terminal ractors	12,141	2,428	2.3%
Forest equipment	12,101	2,420	2.3%
Pumps	9,901	1,980	1.9%
Off-highway trucks	9,377	1,875	1.8%
Cranes	9,356	1,871	1.8%
Scrapers	7,097	1,419	1.4%
Bore/drill rigs	7,047	1,409	1.3%
Irrigation sets	6,835	1,367	1.3%
Rollers	6,055	1,211	1.2%
Other agricultural equipment	5,935	1,187	1.1%
Chippers/grinders	4,669	934	0.9%
Other construction equipment	4,142	828	0.8%
Listed Total		98,480	94.0%
Grand Total		492,398	100.0%

1.2.5 Equipment Using Engines Rated over 560 kW (750 hp)

The largest engines, those rated over 560 kW, are only produced for the nonroad market segments of construction equipment and welders and generators. As much as 35% of the equipment in this power range is manufactured by Caterpillar. Most equipment manufacturers must buy engines from another company. For most power categories, the Power Systems Research database estimates that between 5 and 25 percent of equipment sales are from equipment manufacturers that also produce engines. Since vertically integrated manufacturers are typically very large companies, such as John Deere and Caterpillar, the companies that make up this fraction of the market are in a distinct minority.

As in the previous category, the equipment rated over 560 kW uses mostly turbocharged, direct injection engines that are water-cooled. The leading six manufacturers produce 81% of the equipment in this power range. These manufacturers are shown in Table 1.2-10. Although generator sets make up the majority of equipment sold in this range, a fraction of them are considered stationary, and hence not impacted by the proposed rule. Off-highway trucks , wheel loaders/dozers and crawlers also have significant sales (see Table 1.2-11).

Table 1.2-10
Characterization of the Top 6 Equipment Manufacturers for Engines Rated over 560 kW

Original Equipment Manufacturer	Major Equipment Manufactured	Average Annual Sales	Percentage of Market	Engine Characterization*
Caterpillar	Generator Sets, Off-highway trucks, crawler tractors	1,857	35%	W,T,D
Komatsu	Crawlers, Wheel Loaders/Dozers, Off-Highway Trucks	1,376	26%	W,T,D
Multiquip	Generator Sets	336	6%	W,T,D
Kohler	Generator Sets	335	6%	W,T,D
Cummins	Generator Sets	325	6%	W,T,D
Onis Visa	Generator Sets	107	2%	W,T,D

*W=water-cooled, A=air-cooled,O=oil cooled;NA=naturally aspirated, T=turbocharged, I=indirect injection, D=direct injection.

Table 1.2-11
Equipment Sales Distribution across Applications over 560 kW

Application Description	Five-yr sales Volume (1996-2000)	Average Annual Sales	Percentage of Total Sales
Generator sets	14,237	2,847	54%
Off-highway trucks	4,048	810	15%
Crawlers	3,857	771	15%
Wheel loaders/bulldozers	2,567	513	9.8%
Off-highway tractors	542	108	2.1%
Excavators	371	74	1.4%
Oil field equipment	225	45	0.9%
Chippers/grinders	132	26	0.5%
Listed Total		5,196	99.1%
Grand Total		5,241	100.0%

Section 1.3 characterizes the U.S. petroleum refinery industry, market structure and trends as it pertains to distillate fuels, including nonroad diesel fuel. In addition, it covers refinery operations that are directly impacted by EPA's proposed regulations. Section 1.4 discusses distribution of refined petroleum products through pipelines from refineries, as well as storage operations for these products. Both Sections 1.3 and 1.4 are based on a report prepared by RTI under EPA contract, which is available in the docket.[3]

1.3 Refinery Operations

1.3.1 The Supply-Side

This section describes the supply side of the petroleum refining industry, including the current refinery production processes and raw materials used. It also discusses the need for potential changes in refinery production created by the new EPA rule. Finally, it describes the three primary categories of petroleum products affected by the rule and the ultimate costs of production currently faced by the refineries.

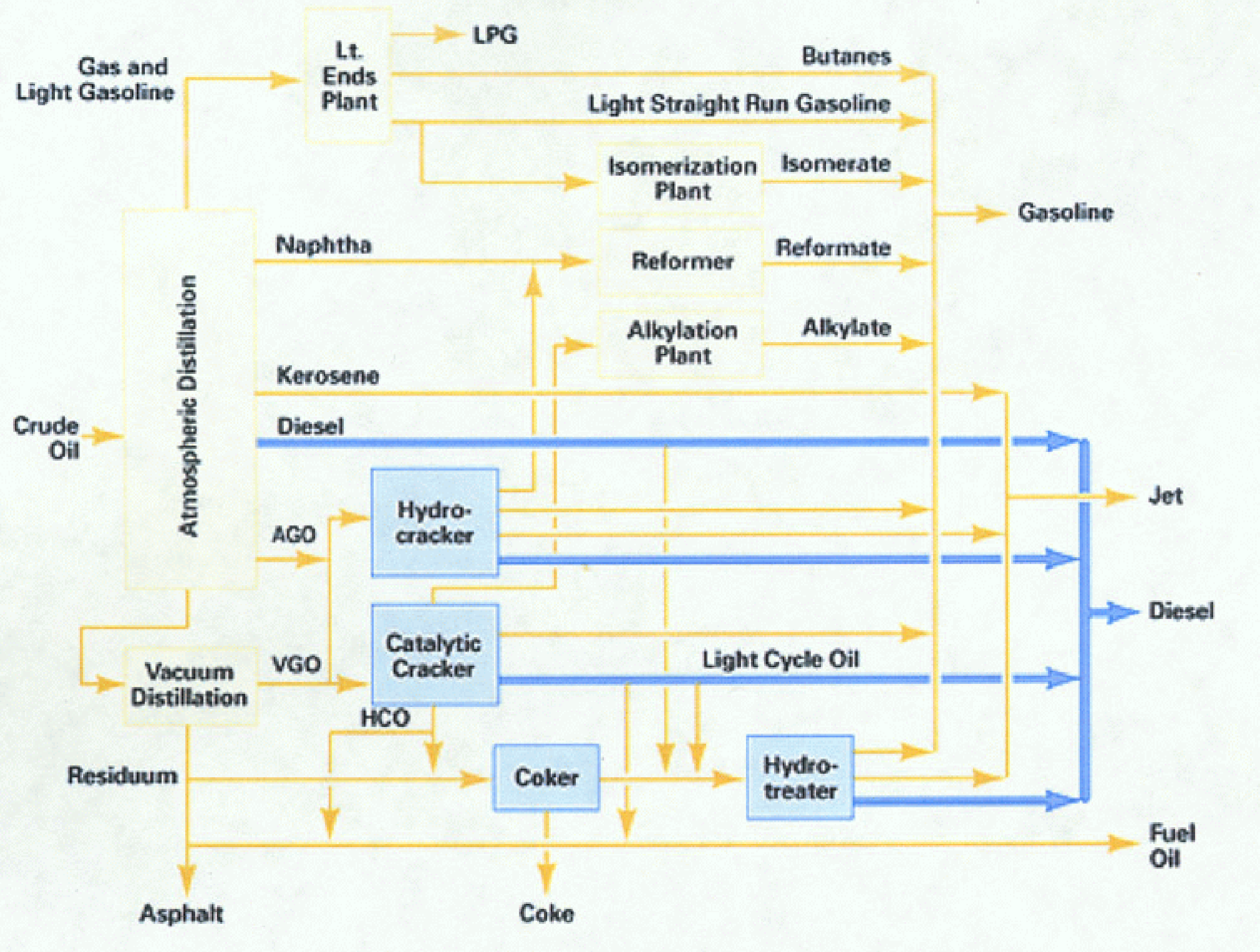
Refinery Production Processes/Technology. Petroleum refining is the thermal and physical separation of crude oil into its major distillation fractions, followed by further processing (through a series of separation and chemical conversion steps) into highly valued finished petroleum products. Although refineries are extraordinarily complex and each site has a unique configuration, we will describe a generic set of unit operations that are found in most medium and large facilities. A detailed discussion of these processes can be found in EPA's sector notebook of the petroleum refining industry (EPA, 1995); simplified descriptions are available on the web sites of several major petroleum producers (Flint Hills Resources, 2002; Chevron, 2002).

Figure 1.3-1 shows the unit operations and major product flows in a typical refinery. After going through an initial desalting process to remove corrosive salts, crude oil is fed to an atmospheric distillation column that separates the feed into several fractions. The lightest boiling range fractions are processed through reforming and isomerization units into gasoline or diverted to lower-value uses such as LPG and petrochemical feedstocks. The middle-boiling fractions make up the bulk of the aviation and distillate fuels produced from the crude. In most refineries, the undistilled liquid (called bottoms) is sent to a vacuum still to further fractionate this heavier material. Bottoms from the vacuum distillation can be further processed into low-value products such as residual fuel oil, asphalt, and petroleum coke.

A portion of the bottoms from the atmospheric distillation, along with distillate from the vacuum still, are processed further in a catalytic cracking unit or in a hydrocracker. These operations break large hydrocarbon molecules into smaller ones that can be converted to high-value gasoline and middle distillate products. Bottoms from the vacuum still are increasingly processed in a coker to produce saleable coke and gasoline and diesel fuel blendstocks. The cracked molecules are processed further in combining operations (alkylation, for example), which combine small molecules into larger, more useful entities, or in reforming, in which petroleum molecules are reshaped into higher quality species. It is in the reforming operation that the octane rating of gasoline is increased to the desired level for final sale. A purification process called hydrotreating helps remove chemically bound sulfur from petroleum products and is critically important for refineries to process their refinery streams into valuable products and to achieve the low sulfur levels that the proposed regulations will mandate.

For each of the major products, several product streams from the refinery will be blended into a finished mixture. For example, diesel fuel will typically contain a straight-run fraction from crude distillation, distillate from the hydrocracker, light-cycle oil from the catalytic cracker, and hydrotreated gas oil from the coker. Several auxiliary unit operations are also needed in the refinery complex, including hydrogen generation, catalyst handing and regeneration, sulfur recovery, wastewater treatment, and blending and storage tanks. Table 1.3-1 shows average yields of major products from U.S. refineries.

Figure 1.3-1
The Modern Refinery



Source: Chevron. 2002. Diesel Fuel Refining and Chemistry. As accessed on August 19, 2002. <www.chevron.com/prodserv/fuels/bulletin/diesel/L2_4_2rf.htm>.

Table 1.3-1
Yields of Major Petroleum Products from Refinery Operations

Product	Gallons per Barrel of Crude	Percentage of Total Feed*
Crude Feed	42.0	100.0%
Gasoline	19.4	46.0%
Highway diesel fuel	6.3	15.0%
Jet Fuel	4.3	10.0%
Petroleum Coke	2.0	5.0%
Residual Fuel Oil	1.9	4.5%
LP Gas	1.9	4.5%
Home heating oil	1.6	4.0%
Asphalt	1.4	3.0%
Nonroad diesel fuel	0.8	2.0%
Other Products	4.0	9.5%
Total	43.6	104.0%

*Note: Total exceeds 100 percent due to volume gain during refining.
Source: Calculated from EIA data in Petroleum Supply Annual 2001. U.S. Department of Energy, Energy Information Administration (EIA). 2002a. Petroleum Supply Annual 2001, Tables 16, 17, and 20. Washington, DC.

Potential Changes in Refining Technology Due to EPA Regulation. Over the next few years, EPA regulations will come into effect that require much lower levels of residual sulfur for both gasoline and highway diesel fuel. To meet these challenges, refineries are planning to add hydrotreater units to their facilities, route more intermediate product fractions through existing hydrotreaters, and operate these units under more severe conditions to reduce levels of chemically bound sulfur in finished products. As has been documented in economic impact analyses for the gasoline and highway diesel rules, these changes will require capital investments for equipment, new piping, and in-process storage; increased use of catalyst and hydrogen; and modifications to current operating strategies.

The addition of lower sulfur limits for nonroad diesel fuel will result in additional refinery changes similar in nature to those required for highway diesel fuel. Product streams formerly sent directly to blending tanks will need to be routed through the hydrotreating operation to reduce their sulfur level. In addition, because an increasing fraction of the total volumetric output of the facility must meet ultra-low sulfur requirements, flexibility will be somewhat reduced. For example, it will become more difficult to sell off spec products if errors or equipment failures occur during operation.

Types of Products. The major products made at petroleum refineries are unbranded commodities, which must meet established specifications for fuel value, density, vapor pressure, sulfur content, and several other important characteristics. As Section 1.3.2 describes, they are transported through a distribution network to wholesalers and retailers, who may attempt to differentiate their fuel from competitors based on the inclusion of special additives or purely through adroit marketing. Gasoline and highway diesel are taxed prior to final sale, whereas nonroad fuel is not. To prevent accidental or deliberate misuse, nonroad diesel fuel must be dyed prior to final sale.

A total of $158 billion of petroleum products were sold in the 1997 census year, accounting for a nontrivial 0.4 percent of GDP. Table 1.3-2 lists the primary finished products produced; as one might expect, the percentages are quite close to the generic refinery output shown in Table 1.3-1. Motor gasoline is the dominant product, both in terms of volume and value, with almost three billion barrels produced in 1997. Distillate fuels accounted for less than half as much as gasoline, with 1.3 billion barrels produced in the U.S. in the same year. Data from the Energy Information Administration (EIA) suggest that 60 percent of that total is low-sulfur highway diesel, with the remainder split between nonroad diesel and heating oil. Jet fuel, a fraction slightly heavier than gasoline, is the third most important product, with a production volume of almost 600 million barrels.

Table 1.3-2
Types of Petroleum Products Produced by U.S. Refineries

Products	Total Produced (thousand barrels)	Percentage of Total
Liquified Refinery Gases	243,322	3.9%
Finished Motor Gasoline	2,928,050	46.4%
Finished Aviation	6,522	0.1%
Jet Fuel	558,319	8.8%
Kerosene	26,679	0.4%
Distillate Fuel Oil	1,348,525	21.4%
Residual Fuel Oil	263,017	4.2%
Naphtha for Feedstock	60,729	1.0%
Other Oils for Feedstock	61,677	1.0%
Special Naphthas	18,334	0.3%
Lubricants	63,961	1.0%
Waxes	6,523	0.1%
Petroleum Coke	280,077	4.4%
Asphalt and Road Oil	177,189	2.8%
Still Gas	244,432	3.9%
Miscellaneous	21,644	0.3%
Total	6,309,000	100.0%

Primary Inputs. Crude oil is the dominant input in the manufacture of refined petroleum products, accounting for 74 percent of material cost, or about $95 billion in 1997, according to the latest Economic Census (U.S. Census Bureau, 1999). The census reported almost equal proportions of imported and domestic crude in that year, with 2.5 billion barrels imported and 2.8 billion barrels originating from within the U.S. More recent data published by the EIA show a higher import dependence in the most recent year, with 3.4 billion barrels, or 61.7 percent, imported out of a total of 5.5 billion barrels used by refineries during 2001 (EIA, 2002a).

Crude oil extracted in different regions of the world have quite different characteristics, including the mixture of chemical species present, density and vapor pressure, and sulfur content. The cost of production and the refined product output mix vary considerably depending on the type of crude processed. A light, sweet crude oil, such as that found in Nigeria, will process very differently from a heavy, sulfur-laden Alaska or Arabian crude. The ease of processing any particular material is reflected in its purchase price, with sweet crudes selling at a premium. The result of these variations is that refineries are frequently optimized to run only certain types of crude; they may be unable or unwilling to switch to significantly different feed materials.

In addition to crude oil, refineries may also feed to their refineries hydrocarbon by-products purchased from chemical companies and other refineries and/or semiprocessed fuel oils imported from overseas. In 1997, the Census reported that these facilities purchased \$11 billion of hydrocarbons and imported \$2.4 billion of unfinished oils. Other significant raw materials purchased include \$600 million for precious metal catalysts and more than \$800 million in additives.

Costs of Production. According to the latest Economic Census, there were 244 petroleum refining establishments in the United States in 1997, owned by 123 companies and employing 64,789 workers. Data from EIA using a more stringent definition shows 164 operable refineries in 1997, a number that fell to 153 by January 1, 2002. As seen in Table 1.3-3, value of shipments in 2000 was \$216 billion, up from \$158 billion in the 1997 census year. The costs of refining are divided into the main input categories of labor, materials, and capital expenditures. Of these categories, the cost of materials represents about 80 percent of the total value of shipments, as defined by the Census, varying from year to year as crude petroleum prices change (see Table 1.3-4). Labor and capital expenditures tend to be more stable, each accounting for 2 to 4 percent of the value of shipments.

Table 1.3-3
Description of Petroleum Refineries—Census Bureau Data

NAICS 324110—Petroleum Refineries	Establishments	Companies	Employment	Value of Shipments ($$10^6$)
2000	(NA)	(NA)	62229	\$215,592
1999	(NA)	(NA)	63619	\$144,292
1998	(NA)	(NA)	64920	\$118,156
1997	244	123	64789	\$157,935
1992 (reported as SIC 2911)	232	132	74800	\$136,239

Sources:
1992 data from U.S. Census Bureau. 1992 Census of Manufactures, Industry Series MC920I-29A. Table 1A.
1997 data from US Census Bureau, 1997 Economic Census - Manufacturing, Industry Series EC97M-3241A, Table 1.
1998-2000 data from US Census Bureau, Annual Survey of Manufactures-2000, 2000, Statistics for Industry Groups and Industries M00(AS)-1, Table 2.

Table 1.3-4
Petroleum Refinery Costs of Production, 1997–2000

Petroleum Refinery Costs of Production	1997	1998	1999	2000
Cost of Materials (10^6)	$127,555	$92,212	$114,131	$178,631
as % of shipment value	80.4%	78.0%	79.1%	82.9%
Cost of Labor (10^6)	$3,885	$3,965	$3,983	$3,995
as % of shipment value	2.4%	3.4%	2.8%	1.9%
Capital Expenditures (10^6)	$4,244	$4,169	$3,943	$4,453
as % of shipment value	2.7%	3.5%	2.7%	2.1%

Source: U.S. Census Bureau, Annual Survey of Manufactures. 2000. 2000 Statistics for Industry Groups and Industries M00(AS)-1, Tables 2 and 5.

Refinery Production Practices. Refining, like most continuous chemical processes, has high fixed costs from the complex and expensive capital equipment installed. In addition, shutdowns are very expensive, because they create large amounts of off-specification product that must be recycled and reprocessed prior to sale. As a result, refineries attempt to operate 24 hours per day, 7 days per week, with only 2 to 3 weeks of downtime per year. Intense focus on cost-cutting has led to large increases in capacity utilization over the past several years. A Federal Trade Commission (FTC) investigation into the gasoline price spikes in the Midwest during the summer of 2000 disclosed an average utilization rate of 94 percent during that year, and EIA data from 2001 show that a 92.6 percent utilization rate was maintained in 2001 (FTC, 2001; EIA, 2002a).

Because of long lead times in procuring and transporting crude petroleum and the need to schedule pipeline shipments and downstream storage, refinery operating strategies are normally set several weeks or months in advance. Once a strategy is established for the next continuous run, it is difficult or impossible to change it. Exact proportions of final products can be altered slightly, but at a cost of moving away from the optimal cost profile established initially. The economic and logistical drivers combine to generate an extremely low supply elasticity. One recent study estimated the supply elasticity for refinery products at 0.24 (Considine, 2002). The FTC study discussed above concluded that refiners had little or no ability to respond to the shortage of oxygenated gasoline in the Midwest in the summer of 2000, even with some advance warning that this would occur.

1.3.2 The Demand Side

This section describes the demand side of the market for refined petroleum products, with a focus on the distillate fuel oil industry. It discusses the primary consumer markets identified and their distribution by end use and PADD. This section also considers substitution possibilities available in each of these markets and the feasibility and costs of these substitutions. Figure 1.3-2 is a map of the five PADD regions.

Uses and Consumers. Gasoline, jet fuel, and distillate fuel oils account for almost 80 percent of the value of refinery product shipments, with gasoline making up about 51 percent (U.S. Census Bureau, 1999). Actual and relative net production volumes of these three major products, along with residual fuel oils, are shown in Table 1.3-5, broken out by PADD and for the country as a whole. PADD III, comprising the states of Texas, Louisiana, Arkansas, Alabama, Mississippi, and New Mexico, is a net exporter of refined products, shipping them through pipelines to consumers on the East Coast and also to the Midwest. Compared to gasoline production patterns, distillate production is slightly lower in PADD V (the West Coast) and higher in PADD II (the Midwest).

The primary end-use markets for distillate and residual fuel oils are divided by EIA as follows:

- residential—primarily fuel oil for home (space) heating;
- commercial—high-sulfur diesel (HSD), low-sulfur diesel (LSD), and fuel oil for space heating;
- industrial—LSD for highway use, HSD for nonroad fuels, and residual fuel oil for operating steam boilers and turbines (power generation);
- oil companies—mostly fuel oil and some residual fuel for internal use;
- farm—almost exclusively HSD;
- electric utility—residual fuel and distillate fuel oil for power generation;
- railroad—HSD and LSD used for locomotives;
- vessel bunking—combination of fuel oil and residual fuel for marine engines;
- on-highway diesel—LSD for highway trucks and automobiles;
- military—HSD sales to the Armed Forces; and
- off-highway diesel—HSD and LSD used in construction and other industries.

Figure 1.3-2
PADD Districts of the United States

Petroleum Administration Defense Districts (PADDs)

As Table 1.3-6 indicates, the highway diesel fuel usage of 33.1 billion gallons represents the bulk of distillate fuel usage (58 percent) in 2000. Residential distillate fuel usage, which in the majority is fuel oil, accounts for 11 percent of total usage in 2000. Nonroad diesel fuel is primarily centered on industrial, farm, and off-highway diesel (construction) usage. In 2000, these markets consumed about 13 percent of total U.S. distillate fuels.

To determine the regional consumption of distillate fuel usage, 2000 sales are categorized by PADDs. As shown in Table 1.3-7, PADD I (the East Coast) consumes the greatest amount of distillate fuel at 20.9 billion gallons. However, residential, locomotive, and vessel bunking consumers account for 6.4 billion gallons of the distillate fuel consumed, which means that at least one-third of the total consumed in PADD I is due to fuel oil and not to diesel fuel consumption.

Table 1.3-5
Refinery Net Production of Gasoline and Fuel Oil Products by PADD

	Motor Gasoline		Distillate Fuel Oil		Jet Fuel		Residual Fuel Oil	
PADD	Quantity (1,000 bbl)	Percent (%)	Quantity (1,000 bbl)	Percent (%)	Quantity (1,000 bbl)	Percent (%)	Quantity (1,000 bbl)	Percent (%)
I	369,750	12.6%	170,109	12.6%	30,831	5.5%	38,473	14.6%
II	641,720	21.9%	316,023	23.4%	80,182	14.4%	24,242	9.2%
III	1,306,448	44.6%	629,328	46.7%	288,749	51.7%	132,028	50.2%
IV	97,869	3.3%	54,698	4.1%	9,787	1.8%	4,151	1.6%
V	512,263	17.5%	178,367	13.2%	148,770	26.6%	64,123	24.4%
Total	2,928,050	100.0%	1,348,525	100.0%	558,319	100.0%	263,017	100.0%

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002a. Petroleum Supply Annual 2001, Tables 16, 17, and 20. Washington, DC. Table 17.

Table 1.3-6
Distillate Fuel Oil by End Use (2000)

End Use	2000 Usage (thousand gallons)	Percentage Share (%)
Residential	6,204,449	10.8%
Commercial	3,372,596	5.9%
Industrial	2,149,386	3.8%
Oil Company	684,620	1.2%
Farm	3,168,409	5.5%
Electric Utility	793,162	1.4%
Railroad	3,070,766	5.4%
Vessel Bunking	2,080,599	3.6%
On-Highway Diesel	33,129,664	57.9%
Military	233,210	0.4%
Off-Highway Diesel	2,330,370	4.1%
Total	57,217,231	100.0%

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2001b. Fuel Oil and Kerosene Sales, 2000, Tables 7-12. Washington, DC.

Table 1.3-7
Distillate Fuel Oil by End Use and PADD

End Use	PADD (Thousand Gallons)				
	I	II	III	IV	V
Residential	5,399,194	628,414	1,117	38,761	136,962
Commercial	2,141,784	568,089	346,578	102,905	213,240
Industrial	649,726	600,800	420,400	241,146	237,313
Oil Company	19,101	41,727	560,905	29,245	33,643
Farm	432,535	1,611,956	552,104	220,437	351,377
Electric Utility	304,717	133,971	194,786	8,492	151,196
Railroad	499,787	1,232,993	686,342	344,586	307,059
Vessel Bunking	490,150	301,356	1,033,333	173	255,586
On-highway Diesel	10,228,244	11,140,616	5,643,703	1,474,611	4,642,490
Military	70,801	36,100	9,250	4,163	112,895
Off-highway Diesel	669,923	608,307	516,989	180,094	355,056
Total	20,905,962	16,904,329	9,965,507	2,644,613	6,796,817

Table 1.3-8 presents a closer look at on-highway consumption of distillate fuel, which is entirely LSD fuel. PADD I (the East Coast) and PADD II (the Midwest) consume almost 65 percent of all U.S. distillate fuel sold for on-highway use.

Table 1.3-9 shows that residential consumption of distillate fuel (primarily fuel oil) is centered in PADD I (the East Coast). Fuel-oil-fired furnaces and water heaters in New York and New England consume most of this heating oil; in most of the rest of the country, residential central heating is almost universally provided by natural gas furnaces or electric heat pumps. A comparison of Tables 1.3-5 and 1.3-9 reveals that PADD I produces far less distillate fuel oil than it consumes. The balance is made up by shipments from PADD III and imports from abroad.

Tables 1.3-10, 1.3-11, and 1.3-12 focus on diesel sales for industrial, agricultural, and construction use. Industrial use of diesel fuel is fairly evenly spread across PADDs. PADD II (the Midwest) has the highest percentage of diesel usage at 28 percent, while PADD V (the West Coast) has the lowest percentage at 11 percent. In contrast, agricultural purchases of diesel are in the great majority (51 percent) centered in PADD II (the Midwest). For construction only, distillate fuel sales are available, but these sales are assumed to be principally diesel fuel. Construction usage of diesel fuel, as with industrial usage, is fairly evenly spread across PADDs, with the exception of PADD IV. PADD IV represents only 8 percent of total construction usage.

Table 1.3-8
Sales for On-Highway Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	10,228,244	30.9%
II	11,140,616	33.6%
III	5,643,703	17.0%
IV	1,474,611	4.5%
V	4,642,490	14.0%
Total	33,129,664	100.0%

Table 1.3-9
Sales for Residential Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	5,399,194	87.0%
II	628,414	10.1%
III	1,117	0.0%
IV	38,761	0.6%
V	136,962	2.2%
Total	6,204,448	100.0%

Table 1.3-10
Industrial Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	649,726	30.2%
II	600,800	28.0%
III	420,400	19.6%
IV	241,146	11.2%
V	237,313	11.0%
Total	2,149,385	100.0%

Table 1.3-11
Adjusted Sales for Farm Use of Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	432,535	13.6%
II	1,611,956	50.9%
III	552,104	17.4%
IV	220,437	7.0%
V	351,377	11.1%
Total	3,168,409	100.0%

Table 1.3-12
Sales for Construction Use of Off-Highway Distillate Fuel by PADD (2000)

PADD	Distillate Usage (Thousand Gallons)	Share of Distillate Fuel Used
I	510,876	26.9%
II	549,299	28.9%
III	394,367	20.8%
IV	150,060	7.9%
V	295,235	15.5%
Total	1,899,837	100.0%

Substitution Possibilities in Consumption. For engines and other combustion devices designed to operate on gasoline, there are no practical substitutes, except among different grades of the same fuel. Because EPA regulations apply equally to all gasoline octane grades, price increases will not lead to substitution or misfueling. In the case of distillate fuels, it is currently possible to substitute between LSD, HSD, and distillate fuel oil, although higher sulfur levels are associated with increased maintenance and poorer performance.

With the consideration of more stringent nonroad fuel and emission regulations, substitution will become less likely. Switching from nonroad ultralow-sulfur diesel (ULSD) to highway ULSD is not financially attractive, because of the taxes levied on the highway product. Misfueling with high-sulfur fuel oil will rapidly degrade the performance of the exhaust system of the affected engine, with negative consequences for maintenance and repair costs.

1.3.3 Industry Organization

To determine the ultimate effects of the EPA regulation, it is important to have a good understanding of the overall refinery industry structure. The degree of industry concentration, regional patterns of production and shipment, and the nature of the corporations involved are all important aspects of this discussion. In this section, we look at market measures for the United States as a whole and by PADD region.

Market Structure—Concentration. There is a great deal of concern among the public about the nature and effectiveness of competition in the refining industry. Large price spikes following supply disruptions and the tendency for prices to slowly fall back to more reasonable levels have created suspicion of coordinated action or other market imperfections in certain regions. The importance of distance in total delivered cost to various end-use markets also means that refiners incur a wide range of costs in serving some markets; because the price is set by the highest cost producer serving the market as long as supply and demand are in balance, profits are made by the low-cost producers in those markets.

There is no convincing evidence in the literature that markets should be modeled as imperfectly competitive, however. Although the FTC study cited earlier concluded that the extremely low supply and demand elasticities made large price movements likely and inevitable given inadequate supply or unexpected increases in demand, their economic analysis found no evidence of collusion or other anticompetitive behavior in the summer of 2000. Furthermore, the industry is not highly concentrated on a nationwide level or within regions. The 1997 Economic Census presented the following national concentration information: four-firm concentration ratio (CR) of 28.5 percent, eight-firm CR of 48.6 percent, and an HHI of 422. Merger guidelines followed by the FTC and Department of Justice consider that there is little potential for pricing power in an industry with an HHI below 1,000.

Two additional considerations were important in making a determination as to whether we can safely assume that refineries act as price-takers in their markets. First, with greater concentration in regional or local markets than at the national level, as well as with significant transport costs, competition from across the country will not be effective in restraining prices. Secondly, several large mergers have occurred since the 1997 Economic Census was conducted, all of which have prompted action by the FTC to ensure that effective competition was retained.

To investigate these issues, RTI estimated concentration measures that are not based on refinery-specific production figures (which are not available), but rather on crude distillation capacity, which is the industry’s standard measure of refinery size. We aggregated the total capacity controlled by each corporate parent, both at the PADD level and nationwide, and then calculated CR-4, CR-8, and HHI figures. The results are presented in Table 1.3-13.

Table 1.3-13
2001 Concentration Measures for Refineries Based on Crude Capacity

PADD	Quantity	CR-4	CR-8	HHI
I	1,879,400	71.6%	91.3%	1,715
II	3,767,449	54.6%	78.2%	1,003
III	8,238,044	48.8%	68.0%	822
IV (current)	606,650	59.6%	90.1%	1,310
IV (future)	606,650	45.4%	80.5%	918
V	3,323,853	61.3%	90.9%	1,199
National	17,815,396	41.89%	65.50%	644

Note: Quantity is crude distillation capacity in thousands of barrels per stream day.
Source:U.S. Department of Energy, Energy Information Administration (EIA). 2002b. Refinery Capacity Data Annual. As accessed on September 23, 2002. http://www.eia.doe.gov/oil_gas/petroleum/data_publications/ refinery_capacity_data/refcap02.dbf. Washington, DC. See text discussion.

The data in this table provide several interesting conclusions:

- The current and future state of PADD IV shows the impact of FTC oversight to maintain competition. As part of approving the Phillips-Conoco merger, the FTC ordered the merged company to divest two refineries in PADD IV—Commerce City, Colorado, and Woods Cross, Utah. Once those divestitures take place, the concentration levels will drop below 1,000, a level that is not generally of concern.
- The only region that is highly concentrated is PADD I, which is generally dominated by two large refineries. In this case, however, imports of finished petroleum products, along with shipments from PADD III, should prevent price-setting behavior from emerging in this market. Table 1.3-14 shows imports of refined products for PADD I and the entire country. About 90 percent of total U.S. imports of gasoline and distillate fuels come into PADD I, aided by inexpensive ocean transport. It is reasonable to assume that any attempts to set prices by the dominant refineries would be defeated with increased imports.

Table 1.3-14
PADD I and Total U.S. Imports of
Gasoline and Fuel Oil Products by Top Five Countries of Origin

Top Five Countries of Origin	Finished Motor Gasoline		Distillate Fuel Oil		Residual Fuel	
	PADD I Import	Total U.S. Import	PADD I Import	Total U.S. Import	PADD I Import	Total U.S. Import
Venezuela	21,017	21,257	16,530	16,530	17,667	18,341
Brazil	8,286	8,286	1,472	1,832	8,361	9,105
Canada	41,711	43,778	30,350	35,165	9,483	11,723
Russia	869	968	10,345	10,345	174	1,051
Virgin Islands, USA	38,135	38,882	30,810	31,540	13,412	13,502
Sum of Top Five	110,018	113,171	89,507	95,412	49,097	53,722
Total	153,633	165,878	112,318	125,586	91,520	107,688
Percentage of Total U.S. Imports	92.6%		89.4%		85.0%	

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2002a. Petroleum Supply Annual 2001. Tables 16, 17, and 20. Washington, DC. Table 20.

- Markets in PADDs II and III, which are not overly concentrated or geographically isolated, should be expected to behave competitively, with little potential for price-setting among its refineries.
- The four large mergers (Exxon-Mobil, BP-Amoco, Chevron-Texaco, and Phillips-Conoco) have not increased nationwide concentration to a level that would be a concern for competitive reasons.

Market Structure—Firms and Facilities. PADD III has the greatest number of refineries affected by the EPA nonroad regulation and will account for the largest volume of new ULSD nonroad fuel. Tables 1.3-15 and 1.3-16 present the number of operating refineries and the number of crude distillation units in each PADD; output volumes were presented in Table 1.3-5. PADD III also accounts for 45 to 50 percent of U.S. refinery net production of finished motor gasoline, distillate fuel oil, and residual fuel oil. Similarly, PADD IV contains the fewest number of affected facilities and accounts for the smallest share of distillate production. Still, because compliance costs per unit of output are likely to depend on refinery scale, the small size and geographic isolation of the PADD IV refineries suggest that the financial impact may be greatest on these operations.

Table 1.3-15
Number of Petroleum Refineries by PADD

PADD	Number of Facilities	Percentage of Total
I	16	11.1%
II	28	19.4%
III	54	37.5%
IV	14	9.7%
V	32	22.2%
Total	144	100.0%

Table 1.3-16
Number of Crude Distillation Facilities by PADD

PADD	Number of Facilities	Percentage of Total
I	12	8.6%
II	26	18.7%
III	50	36.0%
IV	16	11.5%
V	35	25.2%
Total	139	100.0%

According to the EIA Petroleum Supply Annual 2001, the top three owners of crude distillation facilities are ExxonMobil Corp. (11 percent of U.S. total), Phillips Petroleum Corp. (10 percent), and BP PLC (9 percent). Table1.3-17 gives an overview of the top refineries in each PADD, in descending order of total crude distillation capacity. As operating refineries attempt to run at full utilization rates, this measure should correlate directly to total output. Information is not available on actual production of highway diesel, nonroad diesel, and other distillate fuels for each refinery. It should be noted that PADD III has more than 50 percent of the total crude distillation capacity as well as the three largest single facilities.

Firm Characteristics. Many of the large integrated refineries are owned by major petroleum producers, which are among the largest corporations in the United States. According to Fortune Magazine's Fortune 500 list, ExxonMobil is the second largest corporation in the world, as well as in the U.S. Chevron Texaco ranks as the eighth largest U.S. corporation, placing it fourteenth in the world. The newly merged Phillips and Conoco entity will rank in the top 20 in the United States, and six more U.S. petroleum firms make the top 500. BP Amoco (fourth worldwide) and Royal Dutch Shell (eighth worldwide) are foreign-owned, as is Citgo (owned by Petroleos de Venezuela).

Many of the smallest refineries are certified as small businesses by EPA. A total of 21 facilities owned by 13 different parent companies qualify or have applied for small business status (EPA, 2002). These small refineries are concentrated in the Rocky Mountain and Great Plains region of PADD IV, and their conversion to ULSD is likely to require significant flexibility on the part of EPA.

1.3.4 Markets and Trends

There is considerable diversity in how different markets for distillate fuels have been growing over the past several years. Table 1.3-18 shows that residential and commercial use of fuel oil has been dropping steadily since 1984, while highway diesel use has nearly doubled over the same period. Farm use of distillate has been flat over the 15-year period, while off-highway use, mainly for construction, has increased by 40 percent.

Table 1.3-17

Top Refineries in Each PADD by Total Crude Distillation Capacity

	Name of Company	Location of Facilities		Crude Distillation Capacity (barrels/day)	Percentage of Total PADD Crude Distillate Capacity	Percentage of Total U.S. Crude Distillate Capacity
PADD I	Sunoco Inc. (R&M)	Philadelphia	PA	330,000	20.9%	2.0%
	Phillips 66 Co.	Linden	NJ	250,000	15.9%	1.5%
	Phillips 66 Co.	Trainer	PA	180,000	11.4%	1.1%
	Motiva Enterprises LLC	Delaware City	DE	175,000	11.1%	1.1%
	Sunoco Inc.	Marcus Hook	PA	175,000	11.1%	1.1%
	TOTAL			1,576,600	100.0%	9.7%
PADD II	BP Products North America, Inc.	Whiting	IN	410,000	12.0%	2.5%
	Phillips 66 Co.	Wood River	IL	288,300	8.4%	1.8%
	Flint Hills Resources LP	Saint Paul	MN	265,000	7.7%	1.6%
	ExxonMobil Refg & Supply Co.	Joliet	IL	235,500	6.9%	1.4%
	Marathon Ashland Petro LLC	Catlettsburg	KY	222,000	6.5%	1.4%
	Conoco Inc.	Ponca City	OK	194,000	5.7%	1.2%
	Marathon Ashland Petro LLC	Robinson	IL	192,000	5.6%	1.2%
	Williams Refining LLC	Memphis	TN	180,000	5.3%	1.1%
	TOTAL			3,428,053	100.0%	21.1%

(continued)

Figure 1.3-17 (continued)
Top Refineries in Each PADD by Total Crude Distillation Capacity

	Name of Company	Location of Facilities		Crude Distillation Capacity (barrels/day)	Percentage of Total PADD Crude Distillate Capacity	Percentage of Total U.S. Crude Distillate Capacity
PADD III	ExxonMobil Refg & Supply Co.	Baytown	TX	516,500	6.8%	3.2%
	ExxonMobil Refg & Supply Co.	Baton Rouge	LA	488,500	6.4%	3.0%
	BP Products North America, Inc.	Texas City	TX	437,000	5.8%	2.7%
	ExxonMobil Refg & Supply Co.	Beaumont	TX	348,500	4.6%	2.1%
	Deer Park Refg Ltd Ptnrshp	Deer Park	TX	333,700	4.4%	2.1%
	Citgo Petroleum Corp.	Lake Charles	LA	326,000	4.3%	2.0%
	Chevron U.S.A. Inc.	Pascagoula	MS	295,000	3.9%	1.8%
	Flint Hills Resources LP	Corpus Christi	TX	279,300	3.7%	1.7%
	Lyondell Citgo Refining Co. Ltd.	Houston	TX	274,500	3.6%	1.7%
	Premcor Refg Group Inc	Port Arthur	TX	255,000	3.4%	1.6%
	Conoco Inc.	Westlake	LA	252,000	3.3%	1.6%
	Phillips 66 Co.	Belle Chasse	LA	250,000	3.3%	1.5%
	Motiva Enterprises LLC	Port Arthur	TX	245,000	3.2%	1.5%
	Marathon Ashland Petro LLC	Garyville	LA	232,000	3.1%	1.4%
	Motiva Enterprises LLC	Norco	LA	228,000	3.0%	1.4%
	Motiva Enterprises LLC	Convent	LA	225,000	3.0%	1.4%
	Phillips 66 Co.	Sweeny	TX	213,000	2.8%	1.3%
	Valero Refining Co. Texas	Texas City	TX	204,000	2.7%	1.3%
	Chalmette Refining LLC	Chalmette	LA	182,500	2.4%	1.1%
	Atofina Petrochemicals Inc.	Port Arthur	TX	178,500	2.4%	1.1%
	Total			7583080	100.0%	46.7%

(continued)

Figure 1.3-17 (continued)
Top Refineries in Each PADD by Total Crude Distillation Capacity

	Name of Company	Location of Facilities		Crude Distillation Capacity (barrels/day)	Percentage of Total PADD Crude Distillate Capacity	Percentage of Total U.S. Crude Distillate Capacity
PADD IV	Conoco Inc.	Commerce City	CO	62,000	2.0%	0.4%
	Sinclair Oil Corp.	Sinclair	WY	62,000	2.0%	0.4%
	Conoco Inc.	Billings	MO	60,000	1.9%	0.4%
	TOTAL			567,370	18.4%	3.5%
PADD V	BP West Coast Products LLC	Los Angeles	CA	260,000	8.4%	1.6%
	Chevron U.S.A. Inc.	El Segundo	CA	260,000	8.4%	1.6%
	BP West Coast Products LLC	Cherry Point	WA	225,000	7.3%	1.4%
	Chevron U.S.A. Inc.	Richmond	CA	225,000	7.3%	1.4%
	Williams Alaska Petro Inc.	North Pole	AK	197,928	6.4%	1.2%
	TOTAL			3,091,198	100.0%	19.0%
Total U.S.	(excluding Virgin Islands)			16,246,301		100.0%

Source:U.S. Department of Energy, Energy Information Administration (EIA). 2002b. Refinery Capacity Data Annual. As accessed on September 23, 2002. <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcap02.dbf>. Washington, DC.

Table 1.3-18

Sales of Distillate Fuel Oils to End Users 1984-1999 (thousands of barrels per day)

Year	Residential	Commercial	Industrial	Oil Co.	Farm	Electric Utility	Railroad	Vessel Bunkering	Highway Diesel	Military	Off-Highway Diesel	All Other	Total
1984	450	319	153	59	193	45	225	110	1,093	45	109	44	2,845
1985	471	294	169	57	216	34	209	124	1,127	50	105	12	2,868
1986	476	280	175	49	220	40	202	133	1,169	50	111	9	2,914
1987	484	279	190	58	211	42	205	145	1,185	58	113	5	2,976
1988	498	269	170	57	223	52	212	150	1,304	64	119	4	3,122
1989	489	252	167	55	209	70	213	154	1,378	61	107	2	3,157
1990	393	228	160	63	215	48	209	143	1,393	51	116	(s)	3,021
1991	391	226	152	59	214	39	197	141	1,336	54	110	(s)	2,921
1992	406	218	144	51	228	30	209	146	1,391	42	113	(s)	2,979
1993	429	218	128	50	211	38	190	133	1,485	31	127	(s)	3,041
1994	413	218	136	46	209	49	200	132	1,594	34	130	(s)	3,162
1995	416	216	132	36	211	39	208	129	1,668	24	126	—	3,207
1996	436	223	137	41	217	45	213	142	1,754	24	134	—	3,365
1997	423	210	141	41	216	42	200	137	1,867	22	136	—	3,435
1998	367	199	147	37	198	63	185	139	1,967	18	142	—	3,461
1999	381	196	142	38	189	60	182	135	2,091	19	140	—	3,572

Source: U.S. Department of Energy, Energy Information Administration (EIA). 2001a. Annual Energy Review, 2000, Table 5-13. Washington, DC.

1.4 Distribution and Storage Operations

Refined petroleum products, including gasoline, distillates, and jet fuel, are transported by barge and truck and through pipelines from refineries to the wholesale and retail networks in the major markets of the United States. The most important of these routes is the 86,500-mile pipeline network, operated by nearly 200 separate companies (AOPL, 2000; FERC, 2002). Terminals and other storage facilities are located near refineries, along pipelines at breakout stations, and at bulk plants near major consumer markets. There are currently more than 1,300 terminals for refined products in the U.S. (API, 2002).

1.4.1 The Supply-Side

Pipelines are constructed of large-diameter welded steel pipe and typically buried underground. Pumps at the source provide motive force for the 3 to 8 miles per hour flow in the piping network (API, 1998; AOPL, 2000). Periodically, the line pressure is boosted at strategically placed pumping stations, which are often located at breakout points for intermediate distribution of various components. The product is moved rapidly enough to ensure turbulent flow, which prevents back-mixing of components. Figure 1.4-1 shows a typical configuration of several refined components on the Colonial Pipeline, a major artery connecting East Texas producing sites to Atlanta, Charlotte, Richmond, and New Jersey.

The pipelines do not change the physical form of the petroleum products that they carry and only add value by moving the products closer to markets. Operating costs of transporting products in a pipeline are quite small, so most of the cost charged to customers represents amortization of capital costs for construction. According to the 1997 Economic Census, revenues for pipeline transportation, NIACS code 48691, were $2.5 billion, of which only $288 million represented wags and salaries (U.S. Census Bureau, 2000). Almost all pipeline companies act as a common carrier (they do not take ownership of the products they transport), so their revenues and economic value added are equivalent. Census data for storage operations are not broken down in enough detail to permit estimation of revenues or value added.

Figure1.4-1
Typical Sequence in which Products are Batched While in Transit on Colonial System

The most important impact of additional EPA regulation on the distribution network has been to increase the number of different products handled by each pipeline. Although some concern has been expressed by these firms in relation to the gasoline and highway diesel regulations, the incremental effect of reducing sulfur content for nonroad diesel should be minor. The Colonial Pipeline mentioned previously currently handles 38 grades of motor gasoline, 16 grades of distillate products, 7 grades of kerosene-type fuels (including jet fuel), and an intermediate refinery product, light cycle oil (Colonial, 2002).

As Figure1.4-1 shows, these pipelines are shipping low-sulfur gasoline, LSD fuel, and high-sulfur nonroad fuel in the same pipeline. In most cases, the interface (mixing zone) between products is degraded to the poorer quality material. When they begin handling ULSD and gasoline, they may be forced to downgrade more interface material to nonroad or fuel oil and will need to carefully prevent contamination in storage tanks and pumping stations.

Importantly, changeover to ULSD for nonroad applications will not add additional complexity to their operations. EPA expects that there will be no physical difference between 15 ppm diesel fuel destined for the highway market and 15 ppm diesel fuel destined for the off-highway market prior to the terminal level when dye must be added to off-highway diesel fuel to denote its untaxed status. This will allow pipeline operators to ship such fuels in fungible batches. Consequently, the introduction of 15 ppm off-highway diesel should not result in increased difficulty in limiting sulfur contamination during the transportation of ultra-low sulfur products. Pipeline operators will continue to have a market for the downgraded mixing zone material generated during the shipment of 15 ppm diesel fuel by pipeline. After the implementation of EPA’s 15 ppm highway diesel requirement and the envisioned off-highway diesel fuel controls, the pipelines that transport the majority of the nation’s diesel fuel are projected to continue to carry HSD fuel and/or 500 ppm diesel fuel. These pipelines would blend their downgraded 15 ppm diesel into the 500 ppm and/or HSD fuel that they ship. A fraction of the pipelines are projected to carry only a single grade of diesel fuel (15 ppm fuel) after the EPA’s highway program is implemented. These pipelines currently carry only 500 ppm highway diesel fuel. In EPA’s highway diesel final rule, EPA projected that these pipelines would install an additional storage tank to contain the relatively low volumes of downgraded 15 ppm diesel fuel generated during pipeline transportation of the product. EPA projected that this downgraded material would be sold into the off-highway diesel market. The implementation of the envisioned nonroad diesel fuel controls would not change this practice. We expect that these pipeline operators would continue to find a market for the downgraded 15 ppm fuel, either as 500 ppm off-highway diesel fuel or for use in stationary diesel engines.

1.4.2 The Demand-Side

Demand for distribution through pipelines (versus barge or truck movement) is driven by cost differentials with these alternate means of transportation. The National Petroleum Council estimated in a comprehensive 1989 report that water transport of a gallon of petroleum products was about three times as expensive per mile as transport via pipeline, and truck transportation was up to 25 times as expensive per mile (National Petroleum Council, 1989). A recent pipeline industry publication shows that pipelines handle around 60 percent of refined petroleum product movements, with 31 percent transported by water, 5.5 percent by truck, and 3.5 percent by rail (AOPL, 2001).

Pipeline transport charges make up only a small portion of the delivered cost of fuels. Industry publications cite costs of about 1$ per barrel, equal to 2.5 cents per gallon, for a 1600 mile transfer from Houston to New Jersey, and about 2 cents per gallon for a shipment of 1100 miles from Houston to Chicago (AOPL, 2002; Allegro, 2001). Although average hauls are shorter and somewhat more expensive per mile, average transport rates are on the order of 0.06 to 0.18 cents per barrel per mile.

1.4.3 Industry Organization

Just as it has with other transportation modes defined by site-specific assets and high fixed costs, the federal government has traditionally regulated pipelines as common carriers. Unlike railroad and long-haul trucking, however, pipeline transport was not deregulated during the 1980s, and the Federal Energy Regulatory Commission (FERC) still sets allowable tariffs for pipeline movements. A majority of carriers, therefore, compete as regulated monopolies.

Most pipelines are permitted small annual increases in rates without regulatory approval, typically limited to 1 percent less than the increase in the producer price index (PPI). If regulatory changes caused significant cost increases, for instance from the addition of tankage to handle two grades of nonroad diesel fuel, pipeline operators would have to engage in a rate case with FERC to pass their increased costs along to consumers. If they chose not to request rate relief, the pipelines would absorb any costs above the allowable annual increases.

1.4.4 Markets and Trends

Pipeline firms have seen slowly rising demand for their services over the past several years. The latest available data, from the 1996 to 1999 period, are displayed in Table 1.4-1. Pipelines have not only captured almost all of the overall increase in total product movements, but they have taken some share away from water transport during the period. Railroad shipments have grown as well, but from a very small base.

Table 1.4-1
Trends in Transportation of Refined Petroleum Products

					Percentage Change
	1996	**1997**	**1998**	**1999**	**1996-1999**
Pipelines	280.9	279.1	285.7	296.6	5.6%
Water Carriers	154.1	148.3	147.1	147.5	–4.3%
Motor Carriers	28.0	26.0	26.7	27.6	–1.4%
Railroads	16.0	16.2	16.2	18.2	13.8%
Totals	479.0	469.6	475.7	489.9	2.2%

Note: All figures, except percentages, in billions of ton miles.
Source: Association of Oil Pipe Lines (AOPL). 2001. Shifts in Petroleum Transportation. As accessed on November 20, 2002. <www.aopl.org/pubs/facts.html>.

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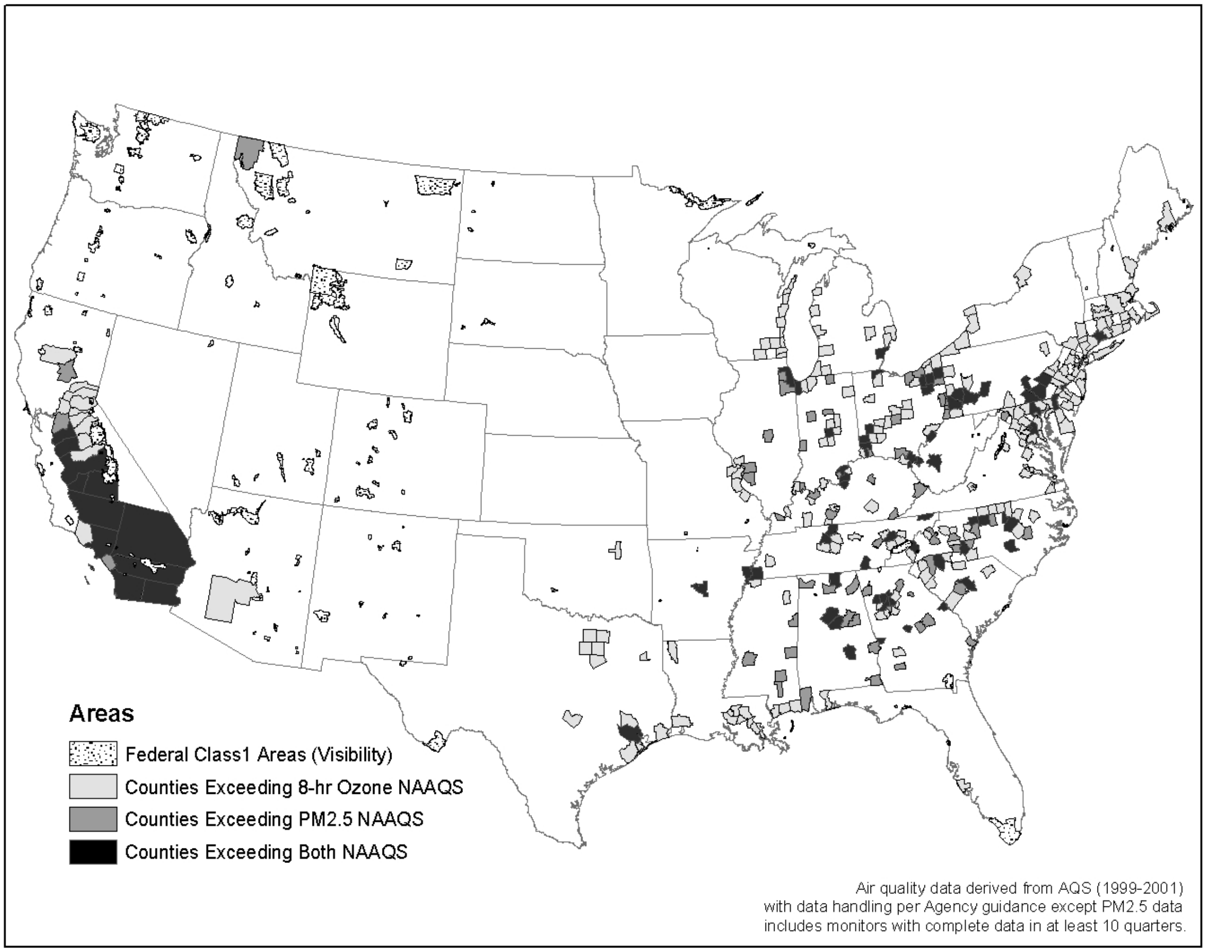
CHAPTER 2: Air Quality, Health, and Welfare Effects

With today's proposal, EPA is acting to extend highway types of emission controls to another major source of diesel engine emissions: nonroad diesel engines. These emissions are significant contributors to atmospheric pollution of particulate matter (PM), ozone and a variety of toxic air pollutants among other pollutants. In our most recent nationwide inventory used for this proposal (1996), the nonroad diesels affected by this proposal contribute over 43 percent of diesel PM emissions from mobile sources, up to 18 percent of total $PM_{2.5}$ emissions in urban areas, and up to 14 percent of NOx emissions in urban areas.

Without further control beyond those standards we have already adopted, by the year 2020, these engines will emit 61 percent of diesel PM from mobile sources, up to 19 percent of all direct $PM_{2.5}$ emissions in urban areas, and up to 20 percent of NOx.emissions in urban areas. When fully implemented, today's proposal would reduce nonroad diesel $PM_{2.5}$ and NOx emissions by more than 90 percent. It will also virtually eliminate nonroad diesel SOx emissions, which amounted to nearly 300,000 tons in 1996, and would otherwise grow to approximately 380,000 tons by 2020.

These dramatic reductions in nonroad emissions are a critical part of the effort by Federal, State, local and Tribal governments to reduce the health related impacts of air pollution and to reach attainment of the National Ambient Air Quality Standard (NAAQS) for PM and ozone, as well as to improve other environmental effects such as visibility. Based on the most recent monitoring data available for this rule (1999-2001), such problems are widespread in the United States. There are over 70 million people living in counties with PM2.5 levels exceeding the PM2.5 NAAQS, and 111 million people living in counties exceeding the 8-hour ozone NAAQS. Figure 2.-1 illustrates the widespread nature of these problems. Shown in this figure are counties exceeding either or both of the two NAAQS plus mandatory Federal Class I areas, which have particular needs for reductions in haze.

Figure 2-1
Nonroad Diesel-related Air Quality Problems are Widespread



Air quality data derived from AQS (1999-2001) with data handling per Agency guidance except PM2.5 data includes monitors with complete data in at least 10 quarters.

As we will describe later in Chapter 9, the air quality improvements expected from this proposal would produce major benefits to human health and welfare, with a combined value in excess of half a trillion dollars between 2007 and 2030. By the year 2030, this proposed rule would be expected to prevent approximately 9,600 deaths per year from premature mortality, and 16,000 nonfatal heart attacks per year. By 2030, it would also prevent 14,000 annual acute bronchitis attacks in children, 260,000 respiratory symptoms in children, nearly 1 million lost work days among adults because of their own symptoms, and 6 million days where adults have to restrict their activities due to symptoms in 2030.

In this chapter we will describe in more detail the air pollution problems associated with emissions from nonroad diesel engines and air quality benefits we expect to realize from the fuel and engine controls in this proposal. The emissions from nonroad diesel engines that are being directly controlled by this rulemaking are NOx, PM and NMHC, and to a lesser extent, CO.

Gaseous air toxics from nonroad diesel engines will also be reduced as a consequence of the proposed standards. In addition, there will be a substantial reduction in SOx emissions resulting from the proposed reduction in sulfur level in diesel fuel. SOx is transformed in the atmosphere to form PM (sulfate).

From a public health perspective, we are primarily concerned with nonroad engine contributions to atmospheric levels of particulate matter in general, diesel PM in particular and various gaseous air toxics emitted by diesel engines, and ozone.[A] We will first review important public health effects caused by these pollutants, briefly describing the human health effects, and we will then review the current and expected future ambient levels of directly or indirectly caused pollution. Our presentation will show that substantial further reductions of these pollutants, and the underlying emissions from nonroad diesel engines, will be needed to protect public health.

Following discussion of health effects, we will discuss a number of welfare effects associated with emissions from diesel engines. These effects include atmospheric visibility impairment, ecological and property damage caused by acid deposition, eutrophication and nitrification of surface waters, environmental threats posed by POM deposition, and plant and crop damage from ozone. Once again, the information available to us indicates a continuing need for further nonroad emission reductions to bring about improvements in air quality.

2.1 Particulate Matter

Particulate matter (PM) represents a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM_{10} refers to particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers. Fine particles refer to those particles with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers (also known as $PM_{2.5}$), and coarse fraction particles are those particles with an aerodynamic diameter greater than 2.5 microns, but less than or equal to a nominal 10 micrometers. Ultrafine PM refers to particles with diameters of less than 100 nanometers (0.1 micrometers). The health and environmental effects of PM are in some cases related to the size of the particles. Specifically, larger particles (> 10 micrometers) tend to be removed by the respiratory clearance mechanisms whereas smaller particles are deposited deeper in the lungs. Also, particulate scatters light obstructing visibility.

The emission sources, formation processes, chemical composition, atmospheric residence times, transport distances and other parameters of fine and coarse particles are distinct. Fine

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[A] Ambient particulate matter from nonroad diesel engine is associated with the direct emission of diesel particulate matter, and with particulate matter formed indirectly in the atmosphere by NOx and SOx emissions (and to a lesser extent NMHC emissions). Both NOx and NMHC participate in the atmospheric chemical reactions that produce ozone.

particles are directly emitted from combustion sources and are formed secondarily from gaseous precursors such as sulfur dioxide, oxides of nitrogen, or organic compounds. Fine particles are generally composed of sulfate, nitrate, chloride, ammonium compounds, organic carbon, elemental carbon, and metals. Nonroad diesels currently emit high levels of NOx which react in the atmosphere to form secondary $PM_{2.5}$ (namely ammonium nitrate). Nonroad diesel engines also emit SO_2 and HC which react in the atmosphere to form secondary $PM_{2.5}$ (namely sulfates and organic carbonaceous $PM_{2.5}$). Combustion of coal, oil, diesel, gasoline, and wood, as well as high temperature process sources such as smelters and steel mills, produce emissions that contribute to fine particle formation. In contrast, coarse particles typically result from mechanical crushing or grinding in both natural and anthropogenic sources. They include resuspended dusts, plant material, and crustal material from paved roads, unpaved roads, construction, farming, and mining activities. Fine particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers, while coarse particles deposit to the earth within minutes to hours and within tens of kilometers from the emission source.

2.1.1 Health Effects of Particulate Matter

Scientific studies show ambient PM (which is attributable to a number of sources including diesel) contributes to a series of adverse health effects. These health effects are discussed in detail in the EPA Air Quality Criteria Document for PM as well as the draft updates of this document released in the past year.[1] In addition, EPA recently released its final “Health Assessment Document for Diesel Engine Exhaust,” which also reviews health effects information related to diesel exhaust as a whole including diesel PM, which is one component of ambient PM.[2]

As detailed in these documents, health effects associated with short-term variation in ambient particulate matter (PM) have been indicated by epidemiologic studies showing associations between exposure and increased hospital admissions for ischemic heart disease,[3] heart failure,[4] respiratory disease,[5, 6, 7, 8] including chronic obstructive pulmonary disease (COPD) and pneumonia.[9, 10, 11] Short-term elevations in ambient PM have also been associated with increased cough, lower respiratory symptoms, and decrements in lung function.[12, 13, 14] Short-term variations in ambient PM have also been associated with increases in total and cardiorespiratory daily mortality in individual cities[15, 16, 17, 18] and in multi-city studies.[19, 20, 21]

Several studies specifically address the contribution of PM from mobile sources in these time-series studies. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death also established a specific influence of mobile source-related $PM_{2.5}$ on daily mortality[22] and a concentration-response function for mobile source-associated $PM_{2.5}$ and daily mortality.[23] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease (CVD). They found that the effect of PM_{10} was significantly greater in areas with a larger proportion of PM_{10} coming from motor vehicles, indicating that PM_{10} from these sources may have a greater effect on the toxicity of ambient PM_{10} when compared with other sources.[24]

Two major cohort studies, the Harvard Six Cities and the ACS studies suggest an association between exposure to ambient PM and premature mortality from cardiorespiratory causes.[25, 26] These are two prospective cohort studies that tracked health outcomes in discrete groups of people over time. Subsequent reanalysis of these studies have confirmed the findings of these articles, and a recent extension of the ACS cohort study found statistically significant increases in lung cancer mortality risk associated with ambient $PM_{2.5}$.[27] This most recent finding is of special interest in this proposal, because of the association of diesel exhaust and lung cancer in occupational studies of varying design.

A number of studies have investigated biological processes and physiological effects that may underlie the epidemiologic findings of earlier studies. This research has found associations between short-term changes in PM exposure with changes in heart beat, force, and rhythm, including reduced heart rate variability (HRV), a measure of the autonomic nervous system's control of heart function.[28, 29, 30, 31, 32, 33] The findings indicate associations between measures of heart function and PM measured over the prior 3 to 24 hours or longer. Decreased HRV has been shown to be associated with coronary heart disease and cardiovascular mortality in both healthy and compromised populations.[34, 35, 36, 37]

Other studies have investigated the association between PM and such systemic factors such as inflammation, blood coagulability and viscosity. It is hypothesized that PM-induced inflammation in the lung may activate a "non-adaptive" response by the immune system, resulting in increased markers of inflammation in the blood and tissues, heightened blood coagulalability, and leukocyte (white blood cell - WBC) count in the blood. A number of studies have found associations between controlled exposure to either concentrated or ambient PM or diesel exhaust exposure and pulmonary inflammation.[38, 39, 40, 41] A number of studies have also shown evidence of increased blood markers of inflammation, such as C-reactive protein, fibrinogen, and white blood cell count associated with inter-day variability in ambient PM.[42, 43, 44, 45] These blood indices have been associated with coronary heart disease and cardiac events such as heart attack.[46, 47] Studies have also shown that repeated or chronic exposures to urban PM were associated with increased severity of atherosclerosis, microthrombus formation, and other indicators of cardiac risk.[48, 49]

The recent studies examining inflammation, heart rate and rhythm in relation to PM provide some evidence into the mechanisms by which ambient PM may cause injury to the heart. New epidemiologic data have indicated that short-term changes in ambient PM mass is associated with adverse cardiac outcomes like myocardial infarction (MI) or ventricular arrythmia.[50, 51] These studies provide additional evidence that ambient $PM_{2.5}$ can cause both acute and chronic cardiovascular injury, which can result in death or non-fatal effects.

Recently, the Health Effects Institute (HEI) reported findings by health researchers at Johns Hopkins University and others that have raised concerns about aspects of the statistical methods used in a number of recent time-series studies of short-term exposures to air pollution and health effects.[52] The estimates derived from the long-term exposure studies, which account for a major share of the economic benefits described in Chapter 9, are not affected. Similarly, the time-series studies employing generalized linear models or other parametric methods, as well as case-crossover studies, are not affected. As discussed in HEI materials provided to EPA and to CASAC, researchers working on the NMMAPS found problems in the default "convergence criteria" used in Generalized Additive Models (GAM) and a separate issue first identified by Canadian investigators about the potential to underestimate standard errors in the same statistical package. These and other scientists have begun to reanalyze the results of several important time series studies with alternative approaches that address these issues and have found a downward revision of some results. For example, the mortality risk estimates for short-term exposure to PM_{10} from NMMAPS were overestimated (this study was not used in this benefits analysis of fine particle effects). However, both the relative magnitude and the direction of bias introduced by the convergence issue is case-specific. In most cases, the concentration-response relationship may be overestimated; in other cases, it may be underestimated. The preliminary reanalyses of the mortality and morbidity components of NMMAPS suggest that analyses reporting the lowest relative risks appear to be affected more greatly by this error than studies reporting higher relative risks.[53, 54]

During the compilation of the draft Air Quality Criteria Document, examination of the original studies used in our benefits analysis found that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions, reduced lower respiratory symptoms, and reduced premature mortality due to short-term PM exposures. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies (Dominici et al, 2002; Schwartz and Zanobetti, 2002; Schwartz, personal communication 2002) suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study.[55] In December 2002, a number of researchers submitted reanalysis reports, and the HEI is currently coordinating review of these reports by a peer review panel. The final report on these reanalyses is expected by the end of April 2003, and the results will be incorporated in the fourth external review draft of the Criteria Document that will be released in summer 2003. While we wait for further clarification from the scientific community, we are not presenting the tables of short-term exposure effects from the draft Air Quality Criteria Document. EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

The long-term exposure health effects of PM are summarized in Table 2.1.1-1 which is taken directly from the draft Air Quality Criteria Document referenced earlier that was released in 2002. This document is continuing to undergo expert and public review.

Table 2.1.1-1
Effect Estimates per Increments[a] in Long-term Mean Levels of Fine and Inhalable Particle Indicators From U.S. and Canadian Studies

Type of Health Effect and Location	Indicator	Change in Health Indicator per Increment in PM[a]	Range of City PM Levels * Means (µg/m^3)
Increased Total Mortality in Adults		**Relative Risk (95% CI)**	
Six City[B]	$PM_{15/10}$ (20 µg/m^3)	1.18 (1.06-1.32)	18-47
	$PM_{2.5}$ (10 µg/m^3)	1.13 (1.04-1.23)	11-30
	$SO_4^=$ (15 µg/m^3)	1.46 (1.16-2.16)	5-13
ACS Study[C] (151 U.S. SMSA)	$PM_{2.5}$ (10 µg/m^3)	1.07 (1.04-1.10)	9-34
	$SO_4^=$ (15 µg/m^3)	1.10 (1.06-1.16)	4-24
Six City Reanalysis[D]	$PM_{15/10}$ (20 µg/m^3)	1.19 (1.06-1.34)	18.2-46.5
	$PM_{2.5}$ (10 µg/m^3)	1.13 (1.04-1.23)	11.0-29.6
ACS Study Reanalysis[D]	$PM_{15/10}$ (20 µg/m^3) (SSI)	1.02 (0.99-1.04)	58.7 (34-101)
	$PM_{2.5}$ (10 µg/m^3)	1.07 (1.04-1.10)	9.0-33.4
ACS Study Extended Analyses[Q]	$PM_{2.5}$ (10 µg/m^3)	1.04 (1.01-1.08)	21.1 (SD=4.6)
Southern California[E]	PM_{10} (50 µg/m^3)	1.242 (0.955-1.616) (males)	51 (±17)
	PM_{10} (cutoff = 30 days/year >100 µg/m^3)	1.082 (1.008-1.162) (males)	
	PM_{10} (50 µg/m^3)	0.879 (0.713-1.085) (females)	51 (±17)
	PM_{10} (cutoff = 30 days/year >100 µg/m^3)	0.958 (0.899-1.021) (females)	
Increased Bronchitis in Children		**Odds Ratio (95% CI)**	
Six City[F]	$PM_{15/10}$ (50 µg/m^3)	3.26 (1.13, 10.28)	20-59
Six City[G]	TSP (100 µg/m^3)	2.80 (1.17, 7.03)	39-114
24 City[H]	H^+ (100 nmol/m^3)	2.65 (1.22, 5.74)	6.2-41.0
24 City[H]	$SO_4^=$ (15 µg/m^3)	3.02 (1.28, 7.03)	18.1-67.3
24 City[H]	$PM_{2.1}$ (25 µg/m^3)	1.97 (0.85, 4.51)	9.1-17.3
24 City[H]	PM_{10} (50 µg/m^3)	3.29 (0.81, 13.62)	22.0-28.6
Southern California[I]	$SO_4^=$ (15 µg/m^3)	1.39 (0.99, 1.92)	—
12 Southern California communities[J] (all children)	PM_{10} (25 µg/m^3) Acid vapor (1.7 ppb)	0.94 (0.74, 1.19) 1.16 (0.79, 1.68)	28.0-84.9 0.9-3.2 ppb
12 Southern California communities[K] (children with asthma)	PM_{10} (19 µg/m^3) $PM_{2.5}$ (15 µg/m^3) Acid vapor (1.8 ppb)	1.4 (1.1, 1.8) 1.4 (0.9, 2.3) 1.1 (0.7, 1.6)	13.0-70.7 6.7-31.5 1.0-5.0 ppb

Table 2.1.1-1 (continued)
Effect Estimates per Increments[a] in Long-term Mean Levels of Fine and Inhalable Particle Indicators From U.S. and Canadian Studies

Type of Health Effect and Location	Indicator	Change in Health Indicator per Increment in PM[a]	Range of City PM Levels * Means (µg/m^3)
Increased Cough in Children		**Odds Ratio (95% CI)**	
12 Southern California communities[J] (all children)	PM_{10} (25 µg/m^3) Acid vapor (1.7 ppb)	1.06 (0.93, 1.21) 1.13 (0.92, 1.38)	28.0-84.9 0.9-3.2 ppb
12 Southern California communities[K] (children with asthma)	PM_{10} (19 µg/m^3) $PM_{2.5}$ (15 µg/m^3) Acid vapor (1.8 ppb)	1.1 (0.0.8, 1.7) 1.3 (0.7, 2.4) 1.4 (0.9, 2.1)	13.0-70.7 6.7-31.5 1.0-5.0 ppb
Increased Obstruction in Adults			
Southern California[L]	PM_{10} (cutoff of 42 days/year >100 µg/m^3)	1.09 (0.92, 1.30)	NR
Decreased Lung Function in Children			
Six City[F]	$PM_{15/10}$ (50 µg/m^3)	NS Changes	20-59
Six City[G]	TSP (100 µg/m^3)	NS Changes	39-114
24 City[M]	H^+ (52 nmoles/m^3)	−3.45% (-4.87, -2.01) FVC	6.2-41.0
24 City[M]	$PM_{2.1}$ (15 µg/m^3)	−3.21% (-4.98, -1.41) FVC	18.1-67.3
24 City[M]	$SO_4^=$ (7 µg/m^3)	−3.06% (-4.50, -1.60) FVC	9.1-17.3
24 City[M]	PM_{10} (17 µg/m^3)	−2.42% (-4.30, -.0.51) FVC	22.0-28.6
12 Southern California communities[N] (all children)	PM_{10} (25 µg/m^3) Acid vapor (1.7 ppb)	−24.9 (-47.2, -2.6) FVC −24.9 (-65.08, 15.28) FVC	28.0-84.9 0.9-3.2 ppb
12 Southern California communities[N] (all children)	PM_{10} (25 µg/m^3) Acid vapor (1.7 ppb)	−32.0 (-58.9, -5.1) MMEF −7.9 (-60.43, 44.63) MMEF	28.0-84.9 0.9-3.2 ppb
12 Southern California communities[O] (4th grade cohort)	PM_{10} (51.5 µg/m^3) $PM_{2.5}$ (25.9 µg/m^3) $PM_{10-2.5}$ (25.6 µg/m^3) Acid vapor (4.3 ppb)	−0.58 (-1.14, -0.02) FVC growth −0.47 (-0.94, 0.01) FVC growth −0.57 (-1.20, 0.06) FVC growth −0.57 (-1.06, -0.07) FVC growth	NR
12 Southern California communities[O] (4th grade cohort)	PM_{10} (51.5 µg/m^3) $PM_{2.5}$ (25.9 µg/m^3) $PM_{10-2.5}$ (25.6 µg/m^3) Acid vapor (4.3 ppb)	−1.32 (-2.43, -0.20) MMEF growth −1.03 (-1.95, -0.09) MMEF growth −1.37 (-2.57, -0.15) MMEF growth −1.03 (-2.09, 0.05) MMEF growth	NR

Table 2.1.1-1 (continued)
Effect Estimates per Increments[a] in Long-term
Mean Levels of Fine and Inhalable Particle Indicators From U.S. and Canadian Studies

Type of Health Effect and Location	Indicator	Change in Health Indicator per Increment in PM[a]	Range of City PM Levels * Means (μg/m^3)
Decreased Lung Function in Adults			
Southern California[P] (% predicted FEV_1, females)	PM_{10} (cutoff of 54.2 days/year >100 μg/m^3)	+0.9 % (-0.8, 2.5) FEV_1	52.7 (21.3, 80.6)
Southern California[P] (% predicted FEV_1, males)	PM_{10} (cutoff of 54.2 days/year >100 μg/m^3)	+0.3 % (-2.2, 2.8) FEV_1	54.1 (20.0, 80.6)
Southern California[P] (% predicted FEV_1, males whose parents had asthma, bronchitis, emphysema)	PM_{10} (cutoff of 54.2 days/year >100 μg/m^3)	−7.2 % (-11.5, -2.7) FEV_1	54.1 (20.0, 80.6)
Southern California[P] (% predicted FEV_1, females)	$SO_4^=$ (1.6 μg/m^3)	Not reported	7.4 (2.7, 10.1)
Southern California[P] (% predicted FEV_1, males)	$SO_4^=$ (1.6 μg/m^3)	−1.5 % (-2.9, -0.1) FEV_1	7.3 (2.0, 10.1)

*Range of mean PM levels given unless, as indicated, studies reported overall study mean (min, max), or mean (±SD); NR=not reported.

[A] Results calculated using PM increment between the high and low levels in cities, or other PM increments given in parentheses; NS Changes = No significant changes.

a Schwartz, J.; Dockery, D. W.; Neas, L. M. (1996) Is daily mortality associated specifically with fine particles? J. Air Waste Manage. Assoc. 46: 927-939.

b Ostro, B. D.; Broadwin, R.; Lipsett, M. J. (2000) Coarse and fine particles and daily mortality in the Coachella Valley, California: a follow-up study. J. Exposure Anal. Environ. Epidemiol. 10: 412-419.

c Lippmann, M.; Ito, K.; Nádas, A.; Burnett, R. T. (2000) Association of particulate matter components with daily mortality and morbidity in urban populations. Cambridge, MA: Health Effects Institute; research report no. 95.

d Lipfert, F. W.; Morris, S. C.; Wyzga, R. E. (2000) Daily mortality in the Philadelphia metropolitan area and size-classified particulate matter. J. Air Waste Manage. Assoc.: 1501-1513.

e Mar, T. F.; Norris, G. A.; Koenig, J. Q.; Larson, T. V. (2000) Associations between air pollution and mortality in Phoenix, 1995-1997. Environ. Health Perspect. 108: 347-353.

f Smith, R. L.; Spitzner, D.; Kim, Y.; Fuentes, M. (2000) Threshold dependence of mortality effects for fine and coarse particles in Phoenix, Arizona. J. Air Waste Manage. Assoc. 50: 1367-1379.

g Fairley, D. (1999) Daily mortality and air pollution in Santa Clara County, California: 1989-1996. Environ. Health Perspect. 107: 637-641.

h Burnett, R. T.; Brook, J.; Dann, T.; Delocla, C.; Philips, O.; Cakmak, S.; Vincent, R.; Goldberg, M. S.; Krewski, D. (2000) Association between particulate- and gas-phase components of urban air pollution and daily mortality in eight Canadian cities. In: Grant, L. D., ed. PM2000: particulate matter and health. Inhalation Toxicol. 12(suppl. 4): 15-39.

i Burnett, R. T.; Cakmak, S.; Brook, J. R.; Krewski, D. (1997) The role of particulate size and chemistry in the association between summertime ambient air pollution and hospitalization for cardiorespiratory diseases. Environ. Health Perspect. 105: 614-620.

j Burnett, R. T.; Smith-Doiron, M.; Stieb, D.; Cakmak, S.; Brook, J. R. (1999) Effects of particulate and gaseous air pollution on cardiorespiratory hospitalizations. Arch. Environ. Health 54: 130-139.

k Tolbert, P. E.; Klein, M.; Metzger, K. B.; Peel, J.; Flanders, W. D.; Todd, K.; Mulholland, J. A.; Ryan, P. B.; Frumkin, H. (2000) Interim results of the study of particulates and health in Atlanta (SOPHIA). J. Exposure Anal. Environ. Epidemiol. 10: 446-460.

l Sheppard, L.; Levy, D.; Norris, G.; Larson, T. V.; Koenig, J. Q. (1999) Effects of ambient air pollution on nonelderly asthma hospital admissions in Seattle, Washington, 1987-1994. Epidemiology 10: 23-30.

m Schwartz, J.; Neas, L. M. (2000) Fine particles are more strongly associated than coarse particles with acute respiratory health effects in schoolchildren. Epidemiology. 11: 6-10.

n Naeher, L. P.; Holford, T. R.; Beckett, W. S.; Belanger, K.; Triche, E. W.; Bracken, M. B.; Leaderer, B. P. (1999) Healthy women's PEF variations with ambient summer concentrations of PM_{10}, $PN_{2.5}$, SO_{42-}, H^+, and O_3. Am. J. Respir. Crit. Care Med. 160: 117-125.

o Zhang, H.; Triche, E.; Leaderer, B. (2000) Model for the analysis of binary time series of respiratory symptoms. Am. J. Epidemiol. 151: 1206-1215.

p Neas, L. M.; Schwartz, J.; Dockery, D. (1999) A case-crossover analysis of air pollution and mortality in Philadelphia. Environ. Health Perspect. 107: 629-631.

q Moolgavkar, S. H. (2000) Air pollution and hospital admissions for chronic obstructive pulmonary disease in three metropolitan areas in the United States. In: Grant, L. D., ed. PM2000: particulate matter and health. Inhalation Toxicol. 12(suppl. 4): 75-90.

Most diesel PM is smaller than 2.5 microns based on extensive emissions characterization studies and as reviewed in the recently release Diesel HAD (Health Assessment Document for Diesel Exhaust).[56, 57] Since there are other sources of PM between the 2.5 to 10 micron range (such as earth crustal material), diesel PM constitutes a smaller fraction of PM_{10} than it does of $PM_{2.5}$. EPA is also evaluating the health effects of PM between 2.5 and 10 microns in the draft revised Air Quality Criteria Document.

In addition to the information in the draft revised Air Quality Criteria Document, further conclusions about health effects associated with mobile source PM on-road diesel engine-generated PM being relevant to nonroad application is supported by the observation in the Diesel HAD that the particulate characteristics in the zone around nonroad diesel engines is likely to be substantially the same as the characteristics of diesel particles in general (such as those found along heavily traveled roadways).

Another body of studies have examined health effects associated with living near a major roads. A recent review of epidemiologic studies examining associations between asthma and roadway proximity concluded that some coherence was evident in the literature, indicating that asthma, lung function decrement, respiratory symptoms, and atopic illness appear to be higher among people living near busy roads.[58] A Dutch cohort study following infants from birth found that traffic-related pollutant concentrations found positive associations with respiratory symptoms, several illnesses, and physician-diagnosed asthma, the last of which was significant for diagnoses prior to 1 year of age.[59] Other studies have shown children living near roads with high truck traffic density have decreased lung function and greater prevalence of lower respiratory symptoms compared to children living on other roads.[60] Another recently published study from Los Angeles found that maternal residence near heavy traffic during pregnancy is associated with adverse birth outcomes, such as preterm birth and low birth weight.[61] However, these studies are not specifically related to PM, but to fresh emissions from mobile sources, which includes other components as well.

Another recent cohort study examined the association between mortality and residential proximity to major roads in the Netherlands. Examining a cohort of 55 to 69 year-olds from 1986 to1994, the study indicated that long-term residence near major roads, an index of exposure to primary mobile source emissions (including diesel exhaust), was significantly associated with increased cardiopulmonary mortality.[62]

Other studies have shown that living near major roads results in substantially higher exposures to ultrafine particles. A British study found that in the lungs of children living near major roads in Leicester, UK, a significantly higher proportion of the alveolar macrophages (WBCs) contained PM compared with children living on quiet streets.[63] All particles observed in the lungs of children were carbon particles under 0.1 um, which are known to be emitted from diesel engines and other mobile sources. This study is consistent with recent studies of ultrafine particle concentrations around major roads in Los Angeles, CA and Minnesota which found that concentrations of the smallest particles were substantially elevated near roadways with diesel traffic.[64, 65, 66]

The particle characteristics in the zone around nonroad diesel engines is not likely to differ substantially from published air quality measurements made along busy roadways. While these studies do not specifically examine nonroad diesel engines, several observations may be drawn. First, nonroad diesel engine emissions are similar in their emission characteristics to on-road motor vehicles. Secondly, exposures from nonroad engines may actually negatively bias these studies, because of exposure misclassification in these studies. Third, certain populations that are exposed directly to fresh nonroad diesel exhaust are exposed at greater concentrations than those found in studies among the general population. These groups include workers in the construction, timber, mining, and agriculture industries, and members of the general population that spend a large amount of time near areas where diesel engine emissions are most densely clustered, such as residents in buildings near large construction sites.

2.1.2 Attainment and Maintenance of the PM_{10} and $PM_{2.5}$ NAAQS: Current and Future Air Quality

2.1.2.1 Current PM Air Quality

There are NAAQS for both PM_{10} and $PM_{2.5}$. Violations of the annual $PM_{2.5}$ standard are much more widespread than are violations of the PM_{10} standards. Emission reductions needed to attain the $PM_{2.5}$ standards will also assist in attaining and maintaining compliance with the PM_{10}

standards. Thus, since most PM emitted by diesel nonroad engines is fine PM, the emission controls proposed today should contribute to attainment and maintenance of the existing PM NAAQS. More broadly, the proposed standards will benefit public health and welfare through reductions in direct diesel PM and reductions of NOx, SOx, and HCs which contribute to secondary formation of PM. As described above, diesel particles from nonroad diesel engines are a component of both coarse and fine PM, but fall mainly in the fine (and even ultrafine) size range.

The reductions from today's proposed rules will assist States as they work with EPA through implementation of local controls including the development and adoption of additional controls as needed to help their areas attain and maintain the standards.

2.1.2.1.1 PM_{10} Levels

The current NAAQS for PM_{10} were first established in 1987. The primary (health-based) and secondary (public welfare based) standards for PM_{10} include both short- and long-term NAAQS. The short-term (24 hour) standard of 150 ug/m^3 is not to be exceeded more than once per year on average over three years. The long-term standard specifies an expected annual arithmetic mean not to exceed 50 ug/m^3 averaged over three years.

Currently, 29.5 million people live in PM_{10} nonattainment areas, including moderate and serious areas. There are presently 58 moderate PM_{10} nonattainment areas with a total population of 6.8 million. The attainment date for the initial moderate PM_{10} nonattainment areas, designated by operation of law on November 15, 1990, was December 31, 1994. Several additional PM_{10} nonattainment areas were designated on January 21, 1994, and the attainment date for these areas was December 31, 2000.

There are 8 serious PM_{10} nonattainment areas with a total affected population of 22.7 million. According to the Act, serious PM_{10} nonattainment areas must attain the standards no later than 10 years after designation. The initial serious PM_{10} nonattainment areas were designated January 18, 1994 and had an attainment date set by the Act of December 31, 2001. The Act provides that EPA may grant extensions of the serious area attainment dates of up to 5 years, provided that the area requesting the extension meets the requirements of Section 188(e) of the Act. Four serious PM_{10} nonattainment areas (Phoenix, Arizona; Coachella Valley, South Coast (Los Angeles), and Owens Valley, California) have received extensions of the December 31, 2001 attainment date and thus have new attainment dates of December 31, 2006.[B] While all of these areas are expected to be in attainment before the emission reductions from this proposed rule are expected to occur, these reductions will be important to assist these areas in maintaining the standards.

Many PM_{10} nonattainment areas continue to experience exceedances. Of the 29.5 million people living in designated PM_{10} nonattainment areas, approximately 25 million people are living in nonattainment areas with measured air quality violating the PM_{10} NAAQS in 1999-2001.

[B] EPA has also proposed to grant Las Vegas, Nevada, an extension until December 31, 2006.

Among these are the seven serious areas listed in Table 2.1.1-2 and 4 moderate areas: Nogales, AZ, Imperial Valley, CA, Mono Basin, CA, and El Paso, TX.

Table 2.1.1-2
Serious PM_{10} Nonattainment Areas

Area	Attainment Date	2000 Population	1999-2001 Measured Violation
Owens Valley, CA	December 31, 2006	7,000	Yes
Phoenix, AZ	December 31, 2006	3,111,876	Yes
Clark County, NV (Las Vegas)	Proposed December 31, 2006	1,375,765	Yes
Coachella Valley, CA	December 31, 2006	225,000	Yes
Los Angeles South Coast Air Basin, CA	December 31, 2006	14,550,521	Yes
San Joaquin Valley, CA	2001	3,080,064	Yes
Walla Walla, WA	2001	10,000	No
Washoe County, NV (Reno)	2001	339,486	Yes
Total Population	22.7 million		

In addition to these designated nonattainment areas, there are 19 unclassified areas, where 8.7 million live, for which States have reported PM_{10} monitoring data for 1999-2001 period indicating a PM_{10} NAAQS violation. Although we do not believe that we are limited to considering only designated nonattainment areas a part of this rulemaking, we have focused on the designated areas in the case of PM_{10}. An official designation of PM_{10} nonattainment indicates the existence of a confirmed PM_{10} problem that is more than a result of a one-time monitoring upset or a result of PM_{10} exceedances attributable to natural events. We have not yet excluded the possibility that one or the other of these is responsible for the monitored violations in 1999-2001 in these 19 unclassified areas. We adopted a policy in 1996 that allows areas whose PM_{10} exceedances are attributable to natural events to remain unclassified if the State is taking all reasonable measures to safeguard public health regardless of the sources of PM_{10} emissions. Areas that remain unclassified areas are not required to submit attainment plans, but we work with each of these areas to understand the nature of the PM_{10} problem and to determine what best can be done to reduce it. The emission reductions from today's proposal would help States improve their PM_{10} air quality levels and maintain the PM_{10} NAAQS.

2.1.2.1.2 $PM_{2.5}$ Levels

The need for reductions in the levels of $PM_{2.5}$ is widespread. Figure 2.1.1-4 below shows $PM_{2.5}$ monitoring data highlighting locations measuring concentrations above the level of the NAAQS. As can be seen from that figure, high ambient levels are widespread throughout the country. In addition, there may be counties without monitors that exceed the level of the standard. A listing of available measurements by county can be found in the air quality technical support document (AQ TSD) for the rule.

The NAAQS for $PM_{2.5}$ were established in 1997 (62 Fed. Reg., 38651, July 18, 1997). The short term (24-hour) standard is set at a level of 65 $\mu g/m^3$ based on the 98th percentile concentration averaged over three years. (The air quality statistic compared to the standard is referred to as the "design value.") The long-term standard specifies an expected annual arithmetic mean not to exceed 15 ug/m^3 averaged over three years.

Current $PM_{2.5}$ monitored values for 1999-2001, which cover counties having about 75 percent of the country's population, indicate that at least 65 million people in 129 counties live in areas where annual design values of ambient fine PM violate the $PM_{2.5}$ NAAQS. There are an additional 9 million people in 20 counties where levels above the NAAQS are being measured, but there are insufficient data at this time to calculate a design value in accordance with the standard, and thus determine whether these areas are violating the $PM_{2.5}$ NAAQS. In total, this represents 37 percent of the counties and 64 percent of the population in the areas with monitors with levels above the NAAQS. Furthermore, an additional 14 million people live in 40 counties that have air quality measurements within 10 percent of the level of the standard. These areas, although not currently violating the standard, will also benefit from the additional reductions from this rule in order to ensure long term maintenance.

Figure 2.1.1-4 is a map of currently available $PM_{2.5}$ monitoring data, highlighting monitor locations near or above the annual PM2.5 NAAQS. As can be seen from this figure, high ambient levels are widespread throughout the East and California.

Figure 2.1.1-5 graphically presents the numbers of people currently exposed to various unhealthy levels of $PM_{2.5}$.[67] As shown in Table 2.1.1-3 of the 74 million people currently living in counties with measurements above the NAAQS, 22 million live in counties above 20 ug/m^3. In Section 2.1.2.2, we discuss that absent additional controls, our modeling predicts there will continue to be large numbers of people living in counties with PM levels above the standard.

Table 2.1.1-3
1999/2001 Monitored Population[a] Living in Counties with Annual Average[b] $PM_{2.5}$ Concentrations Shown (70 Percent of Total U.S. Population)

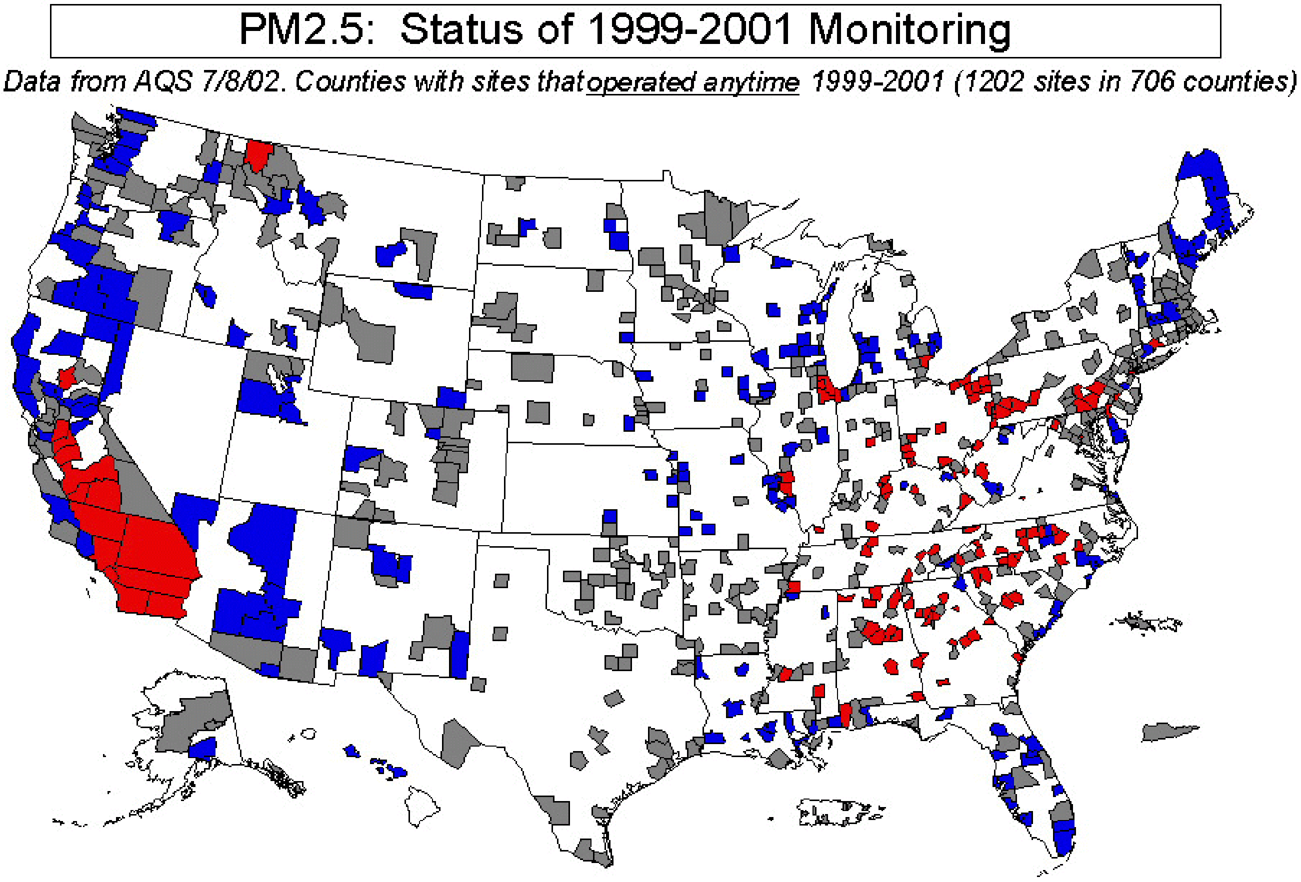
Measured 1999/2000 Annual Average $PM_{2.5}$ Concentration (µg/m3) (A)	Number of Counties Within The Concentration Range	2000 Population Living in Monitored Counties Within The Concentration Range (Millions, 2000 Census Data) (B)	Cumulative Percent of 2000 Monitored Population Living in Counties Within The Concentration Range[c] (C)
>25	3	12.8	7
>20 <=25	10	9.2	5
>15 <=20	136	52.3	27
<=15	402	115.6	61

[a] Monitored population estimates represent populations living in monitored counties (with community based monitors) based on monitors with at least 10 quarter with at least 11 samples per quarter between 1999 and 2001.

[b] Annual average represents the monitor reading with the highest average in each monitored county.

[c] The monitored population is 189.2 million (as reflected in column C, where C=B/Monitored Population). Total monitored population is 191 million; the Census total county-based 2000 population is 272.7 million.

Figure 2.1.1-4
Current Fine PM Monitoring Data



PM2.5: Status of 1999-2001 Monitoring

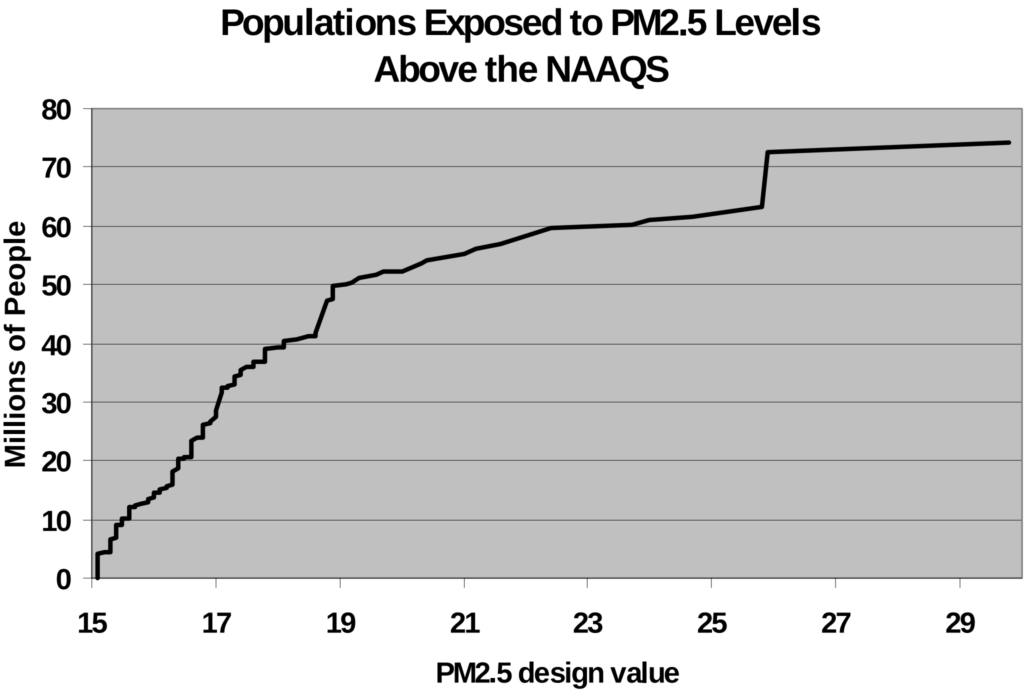
Data from AQS 7/8/02. Counties with sites that operated anytime 1999-2001 (1202 sites in 706 counties)

🟥 Counties with at least 1 complete site w/ d.v. > 15.0 **[129]**

🟦 Counties with at least 1 complete site w/ d.v. ≤ 15.0 (and none above) [182]

⬛ Counties without a complete site [395]

Figure 2.1.1-5

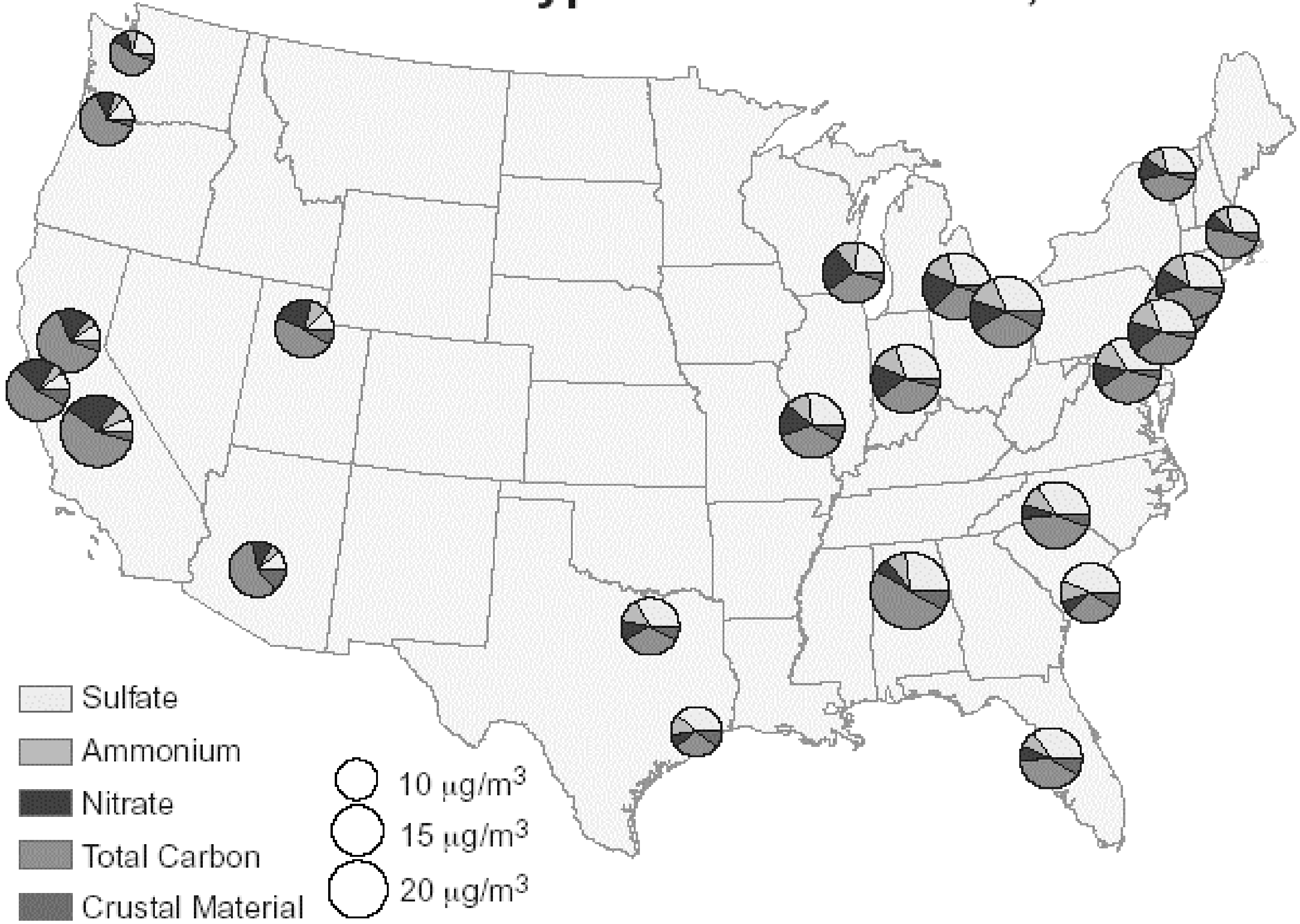


The relative contribution of various chemical components to $PM_{2.5}$ varies by region of the country. Data on $PM_{2.5}$ composition are available from the EPA Speciation Trends Network in 2001 and the IMPROVE Network in 1999 covering both urban and rural areas in numerous regions of the U. S. These data show that carbonaceous $PM_{2.5}$ makes up the major component for $PM_{2.5}$ in both urban and rural areas in the Western U.S. Carbonaceous $PM_{2.5}$ includes both elemental and organic carbon. Nitrates formed from NOx also plays a major role in the western U.S., especially in the California area where it is responsible for about a quarter of the ambient $PM_{2.5}$ concentrations. Sulfate plays a lesser role in these regions by mass, but it remains important to visibility impairment discussed below. For the Eastern and mid U.S., these data show that both sulfates and carbonaceous $PM_{2.5}$ are major contributors to ambient $PM_{2.5}$ both urban and rural areas. In some eastern areas, carbonaceous $PM_{2.5}$ is responsible for up to half of ambient $PM_{2.5}$ concentrations. Sulfate is also a major contributor to ambient $PM_{2.5}$ in the Eastern U.S. and in some areas make greater contributions than carbonaceous $PM_{2.5}$.

Nonroad engines, especially nonroad diesel engines, contribute significantly to ambient $PM_{2.5}$ levels, largely through emissions of carbonaceous $PM_{2.5}$. Carbonaceous $PM_{2.5}$ is a major portion of ambient $PM_{2.5}$, especially in populous urban areas. Much of the total carbon PM excess is organic carbon. Nonroad diesels also emit high levels of NOx which react in the atmosphere to form secondary $PM_{2.5}$ (namely ammonium nitrate). Nonroad diesel engines also emit SO_2 and HC which react in the atmosphere to form secondary $PM_{2.5}$ (namely sulfates and organic carbonaceous $PM_{2.5}$). Figure 2.1.1-1 shows the levels and composition of ambient $PM_{2.5}$ in some urban areas.

Figure 2.1.1-2 shows the levels and composition of $PM_{2.5}$ in rural areas where the total $PM_{2.5}$ levels are generally lower. From Figures 2.1.1-1 and 2.1.1-2, one can compare the levels and composition of $PM_{2.5}$ in various urban areas and a corresponding rural area. This comparison, in Figure 2.1.1-3, shows that much of the excess $PM_{2.5}$ in urban areas (annual average concentration at urban monitor minus annual average concentration at corresponding rural monitor) is indeed from carbonaceous PM.[68, 69] See the AQ TSD for details.

Figure 2.1.1-1



Annual Average PM$_{2.5}$ Concentrations (µg/m^3) and Particle Type in Urban Areas, 2001

Source: EPA Speciation Network, 2001.

Figure 2.1.1-2

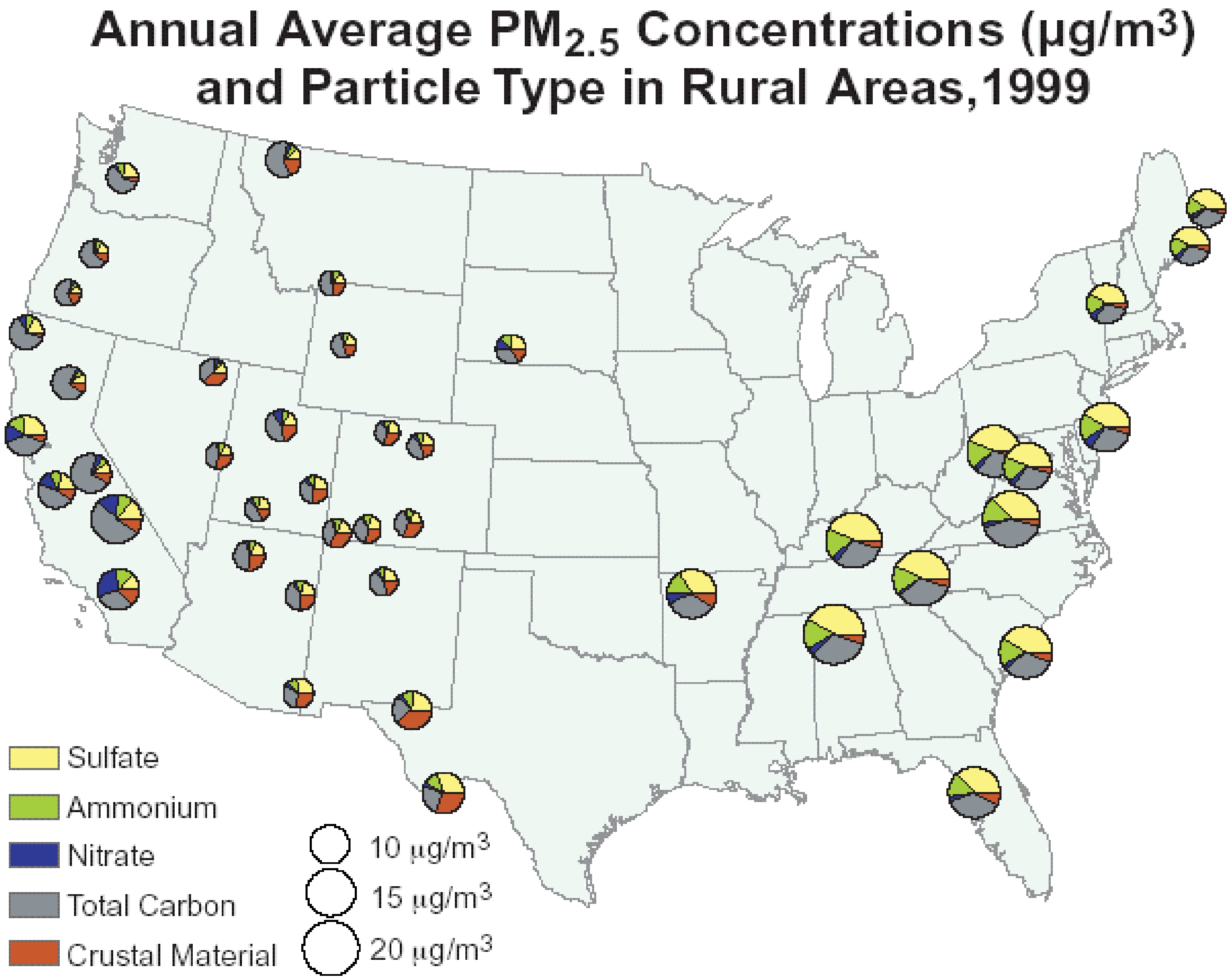
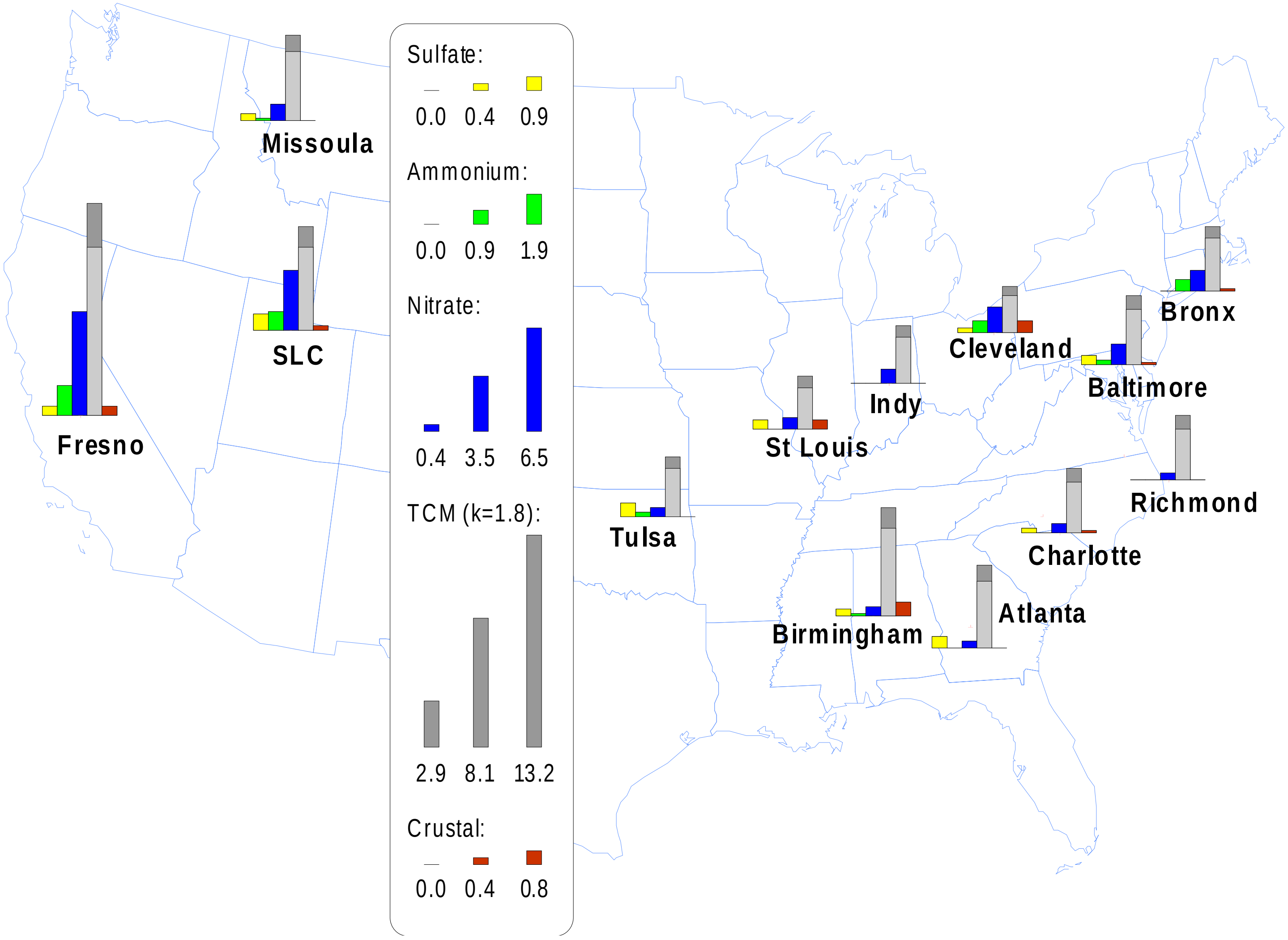

Annual Average PM2.5 Concentrations (µg/m3) and Particle Type in Rural Areas,1999
Sulfate
Ammonium
Nitrate
Total Carbon
Crustal Material
10 µg/m3
15 µg/m3
20 µg/m3

Figure 2.1.1-3
Composition of Urban Excess $PM_{2.5}$ at Selected Sites, 1999
(Source: U.S. EPA (2003) AQ TSD;Roa and Frank 2003)



The ambient PM monitoring networks account for both directly emitted PM as well as secondarily formed PM. Emission inventories, which account for directly emitted PM and PM precursors separately, also show that mobile source PM emissions, including that from nonroad diesel engines, is a major contributor to total PM emissions. Nationally, the proposed standards would significantly reduce emissions of carbonaceous PM. NOx emissions, a prerequisite for formation of secondary nitrate aerosols, will also be reduced. Nonroad diesel engines are major contributors to both of these pollutants. The proposed standards will also reduce SOx and VOC. Nonroad diesel engines emissions also contribute to national SOx and VOC emissions inventories, but to a lesser degree than for PM and NOx. The emission inventories are discussed in detail in Chapter 3.

As discussed in Sections 2.2.2.6 and 2.1, diesel PM also contains small quantities of numerous mutagenic and carcinogenic compounds associated with the particles (and also organic gases). In addition, while toxic trace metals emitted by nonroad diesel engines represent a very small portion of the national emissions of metals (less than one percent) and a small portion of diesel PM (generally less than one percent of diesel PM), we note that several trace metals of potential toxicological significance and persistence in the environment are emitted by diesel engines. These trace metals include chromium, manganese, mercury and nickel. In addition, small amounts of dioxins have been measured in highway engine diesel exhaust, some of which may partition into the particulate phase; dioxins are a major health concern but diesel engines are a minor contributor to overall dioxin emissions. Diesel engines also emit polycyclic organic matter (POM), including polycyclic aromatic hydrocarbons (PAH), which can be present in both gas and particle phases of diesel exhaust. Many PAH compounds are classified by EPA as probable human carcinogens.

2.1.2.2 Risk of Future Violations

2.1.2.2.1 PM Air Quality Modeling and Methods

In conjunction with this rulemaking, we performed a series of PM air quality modeling simulations for the continental U.S. The model simulations were performed for five emissions scenarios: a 1996 baseline projection, a 2020 baseline projection and a 2020 projection with nonroad controls, a 2030 baseline projection and a 2030 projection with nonroad controls. Further discussion of this modeling, including evaluations of model performance relative to predicted future air quality, is provided in the AQ Modeling TSD.

The model outputs from the 1996, 2020 and 2030 baselines, combined with current air quality data, were used to identify areas expected to exceed the $PM_{2.5}$ NAAQS in 2020 and 2030. These areas became candidates for being determined to be residual exceedance areas which will require additional emission reductions to attain and maintain the $PM_{2.5}$ NAAQS. The impacts of the nonroad controls were determined by comparing the model results in the future year control runs against the baseline simulations of the same year. This modeling supports the conclusion that there is a broad set of areas with predicted $PM_{2.5}$ concentrations at or above 15 ug/m^3 between 1996 and 2030 in the baseline scenarios without additional emission reductions.

The air quality modeling performed for this rule was based upon an improved version of the modeling system used in the HD Engine/Diesel Fuel rule (to address peer-review comments) with the addition of updated inventory estimates for 1996, 2020 and 2030.

A national-scale version of the REgional Model System for Aerosols and Deposition (REMSAD) was utilized to estimate base and future-year PM concentrations over the contiguous U.S. for the various emissions scenarios. Version 7 of REMSAD was used for this proposed rule. REMSAD was designed to calculate the concentrations of both inert and chemically reactive pollutants in the atmosphere that affect annual particulate concentrations and deposition over large spatial scales.[C] Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, REMSAD is useful for evaluating the impacts of the proposed rule on U.S. PM concentrations. The following sections provide an overview of the PM modeling completed as part of this rulemaking. More detailed information is included in the AQ Modeling TSD, which is located in the docket for this rule.

The PM air quality analyses employed the modeling domain used previously in support of Clear Skies air quality assessment. The domain encompasses the lower 48 States and extends from 126 degrees to 66 degrees west longitude and from 24 degrees to 52 degrees north latitude. The model contains horizontal grid-cells across the model domain of roughly 36 km by 36 km. There are 12 vertical layers of atmospheric conditions with the top of the modeling domain at 16,200 meters.

The simulation periods modeled by REMSAD included separate full-year application for each of the five emissions scenarios (1996 base year, 2020 base, 2020 control, 2030 baseline, 2030 control) using the 1996 meteorological inputs described below.

The meteorological data required for input into REMSAD (wind, temperature, surface pressure, etc.) were obtained from a previously developed 1996 annual run of the Fifth-Generation National Center for Atmospheric Research (NCAR) / Penn State Mesoscale Model (MM5). A postprocessor called MM5- REMSAD was developed to convert the MM5 data into the appropriate REMSAD grid coordinate systems and file formats. This postprocessor was used to develop the hourly average meteorological input files from the MM5 output. Documentation of the MM5REMSAD code and further details on the development of the input files is contained in Mansell (2000).[70] A more detailed description of the development of the meteorological input data is provided in the AQ Modeling TSD, which is located in the docket for this rule.

The modeling specified initial species concentrations and lateral boundary conditions to approximate background concentrations of the species; for the lateral boundaries the concentrations varied (decreased parabolically) with height. These initial conditions reflect

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[C] Given the potential impact of the porposed rule on secondarily formed particles it is important to employ a Eulerian model such as REMSAD. The impact of secondarily formed pollutants typically involves primary precursor emissions from a multitude of widely dispersed sources, and chemical and physical processes of pollutants that are best addressed using an air quality model that employs an Eulerian grid model design.

relatively clean background concentration values. Terrain elevations and land use information was obtained from the U.S. Geological Survey database at 10 km resolution and aggregated to the roughly 36 km horizontal resolution used for this REMSAD application. The development of model inputs is discussed in greater detail in the AQ Modeling TSD, which is available in the docket for this rule.

2.1.2.2.2 Model Performance Evaluation

The purpose of the base year PM air quality modeling was to reproduce the atmospheric processes resulting in formation and dispersion of fine particulate matter across the U.S. An operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon etc.) for 1996 was performed in order to estimate the ability of the modeling system to replicate base year concentrations.

This evaluation is comprised principally of statistical assessments of model versus observed pairs. The robustness of any evaluation is directly proportional to the amount and quality of the ambient data available for comparison. Unfortunately, there are few $PM_{2.5}$ monitoring networks with available data for evaluation of the Nonroad PM modeling. Critical limitations of the existing databases are a lack of urban monitoring sites with speciated measurements and poor geographic representation of ambient concentration in the Eastern U.S.

The largest available ambient database for 1996 comes from the IMPROVE network. IMPROVE is a cooperative visibility monitoring effort between EPA, federal land management agencies, and state air agencies. Data are collected at Class I areas across the U.S. mostly at national parks, national wilderness areas, and other protected pristine areas.[71] There were approximately 60 IMPROVE sites that had complete annual $PM_{2.5}$ mass and/or $PM_{2.5}$ species data for 1996. Using the 100th meridian to divide the Eastern and Western U.S., 42 sites were located in the West and 18 sites were in the East.

The observed IMPROVE data used for the performance evaluation consisted of $PM_{2.5}$ total mass, sulfate ion, nitrate ion, elemental carbon, organic aerosols, and crustal material (soils). The REMSAD model output species were postprocessed in order to achieve compatibility with the observation species.

The principal evaluation statistic used to evaluate REMSAD performance is the “ratio of the means”. It is defined as the ratio of the average predicted values over the average observed values. The annual average ratio of the means was calculated for five individual $PM_{2.5}$ species as well as for total $PM_{2.5}$ mass. The metrics were calculated for all IMPROVE sites across the country as well as for the East and West individually. Table 2.1.2-1 shows the ratio of the annual means. Numbers greater than 1 indicate overpredictions compared to ambient observations (e.g. 1.23 is a 23 percent overprediction). Numbers less than 1 indicate underpredictions.

Table 2.1.2-1
Model Performance Statistics for REMSAD $PM_{2.5}$ Species Predictions: 1996 Base Case

IMPROVE PM Species	Ratio of the Means (annual average concentrations)		
	Nationwide	Eastern U.S.	Western U.S.
$PM_{2.5}$, total mass	0.68	0.85	0.51
Sulfate ion	0.81	0.9	0.61
Nitrate ion	1.05	1.82	0.45
Elemental carbon	1.01	1.23	0.8
Organic aerosols	0.55	0.58	0.53
Soil/Other	1.38	2.25	0.88

Note: The dividing line between the West and East was defined as the 100th meridian.

When considering annual average statistics (e.g., predicted versus observed), which are computed and aggregated over all sites and all days, REMSAD underpredicts fine particulate mass ($PM_{2.5}$) by roughly 30 percent. $PM_{2.5}$ in the Eastern U.S. is slightly underpredicted, while $PM_{2.5}$ in the West is underpredicted by about 50 percent. Eastern sulfate is slightly underpredicted, elemental carbon is slightly overpredicted, while nitrate and crustal are largely overpredicted. This is balanced by an underprediction in organic aerosols. Overall the $PM_{2.5}$ performance in the East is relatively unbiased due to the dominance of sulfate in the observations. Western predictions of sulfate, nitrate, elemental carbon, and organic aerosols are all underpredicted.

REMSAD performance is relatively good in the East. The model is overpredicting nitrate, but less so than in previous model applications. The overpredictions in soil/other concentrations in the East can largely be attributed to overestimates of fugitive dust emissions. The model is performing well for sulfate which is the dominant $PM_{2.5}$ species in most of the East. Organic aerosols are underpredicted in both the East and West. There is a large uncertainty in the current primary organic inventory as well as the modeled production of secondary organic aerosols.

REMSAD is underpredicting all species in the West. The dominant species in the West is organic aerosols. Secondary formation of sulfate, nitrate, and organics appears to be underestimated in the West. Additionally, the current modeling inventory does not contain wildfires, which may be a significant source of primary organic carbon in the West.

It should be noted that $PM_{2.5}$ modeling is an evolving science. There have been few regional or national scale model applications for primary and secondary PM. Unlike ozone modeling, there is essentially no database of past performance statistics against which to measure the performance of this modeling. Given the state of the science relative to PM modeling, it is inappropriate to judge PM model performance using criteria derived for other pollutants, like ozone. Still, the performance of this air quality modeling is encouraging, especially considering that the results are limited by our current knowledge of PM science and chemistry, and by the emissions inventories for primary PM and secondary PM precursor pollutants. EPA and others are only beginning to understand the limitations and uncertainties in the current inventories and modeling tools. Improvements to the tools are being made on a continuing basis.

2.1.2.2.3 Results with Areas at Risk of Future $PM_{2.5}$ Violations

Our air quality modeling performed for this proposal also indicates that the present widespread number of counties with annual averages above 15 ug/m^3 are likely to persist in the future in the absence of additional controls. For example, in 2020 based on emission controls currently adopted or expected to be in place, we project that 66 million people will live in 79 counties with average $PM_{2.5}$ levels at and above 15 ug/m^3. In 2030, the number of people projected to live in areas exceeding the $PM_{2.5}$ standard is expected to increase to 85 million in 107 counties. An additional 24 million people are projected to live in counties within 10 percent of the standard in 2020, which will increase to 64 million people in 2030. The AQ Modeling TSD lists the specifics.

Our modeling also indicates that the reductions we are expecting from today's proposal will make a substantial contribution to reducing these exposures.[D] In 2020, the number of people living in counties with $PM_{2.5}$ levels above the NAAQS would be reduced from 66 million to 60 million living in 67 counties. That is a reduction of 9 percent in exposed population and 15 percent of the number of counties. In 2030, there would be a reduction from 85 million people to 71 million living in 84 counties. This represents an even greater improvement than projected for 2020 because of the fleet turnover and corresponds to a 16 percent reduction in exposed population and a 21 percent of the number of counties. Furthermore, our modeling also shows that the emission reductions would assist areas with future maintenance of the standards.

Table 2.1.2-2 lists the counties with 2020 and 2030 projected annual $PM_{2.5}$ design values that violate the annual standard. Counties are marked with an "V" in the table if their projected design values are greater than or equal to 15.05 ug/m^3. The current 3-year average design values of these counties are also listed. Recall that we project future design values only for counties that have current design values, so this list is limited to those counties with ambient monitoring data sufficient to calculate current 3-year design values.

Table 2.1.2-2
Counties with 2020 and 2030 Projected Annual PM2.5
Design Values in Violation of the Annual PM2.5 Standard.[a]

[D] The results illustrate the type of PM changes for the preliminary control option, as discussed in the Draft RIA in Section 3.6. The proposal differs from the modeled control case based on updated information; however, we believe that the net results would approximate future emissions, although we anticipate the PM reductions might be slightly smaller.

State	County	1999 - 2001 Design Value (ug/m^3)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
AL	De Kalb	16.8			V	V	64,452
AL	Houston	16.3	V		V	V	88,787
AL	Jefferson	21.6	V	V	V	V	662,047
AL	Mobile	15.3			V	V	399,843
AL	Montgomery	16.8	V	V	V	V	223,510
AL	Morgan	19.1	V	V	V	V	111,064
AL	Russell	18.4	V	V	V	V	49,756
AL	Shelby	17.2	V	V	V	V	143,293
AL	Talladega	17.8	V	V	V	V	80,321
CA	Fresno	24	V	V	V	V	799,407
CA	Imperial	15.7			V		142,361
CA	Kern	23.7	V	V	V	V	661,645
CA	Los Angeles	25.9	V	V	V	V	9,519,338
CA	Merced	18.9	V	V	V	V	210,554
CA	Orange	22.4	V	V	V	V	2,846,289
CA	Riverside	29.8	V	V	V	V	1,545,387
CA	San Bernardino	25.8	V	V	V	V	1,709,434
CA	San Diego	17.1	V	V	V	V	2,813,833
CA	San Joaquin	16.4			V		563,598
CA	Stanislaus	19.7	V	V	V	V	446,997
CA	Tulare	24.7	V	V	V	V	368,021
CT	New Haven	16.8	V	V	V	V	824,008
DE	New Castle	16.6	V	V	V	V	500,265
DC	Washington	16.6	V	V	V	V	572,059
GA	Bibb	17.6	V	V	V	V	153,887
GA	Chatham	16.5	V	V	V	V	232,048
GA	Clarke	18.6	V	V	V	V	101,489
GA	Clayton	19.2	V	V	V	V	236,517
GA	Cobb	18.6	V	V	V	V	607,751
GA	De Kalb	19.6	V	V	V	V	665,865
GA	Dougherty	16.6	V	V	V	V	96,065
GA	Floyd	18.5	V	V	V	V	90,565
GA	Fulton	21.2	V	V	V	V	816,006
GA	Hall	17.2	V		V	V	139,277
GA	Muscogee	18	V	V	V	V	186,291
GA	Paulding	16.8	V	V	V	V	81,678
GA	Richmond	17.4	V	V	V	V	199,775
GA	Washington	16.5	V	V	V	V	21,176
GA	Wilkinson	18.1	V	V	V	V	10,220
IL	Cook	18.8	V	V	V	V	5,376,741
IL	Du Page	15.4			V		904,161
IL	Madison	17.3	V	V	V	V	258,941
IL	St Clair	17.4	V	V	V	V	256,082

State	County	1999 - 2001 Design Value (ug/m^3)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
IL	Will	15.9	V		V	V	502,266
IN	Clark	17.3	V	V	V	V	96,472
IN	Lake	16.3	V	V	V	V	484,564
IN	Marion	17	V		V	V	860,454
IN	Vanderburgh	16.9			V		171,922
KY	Jefferson	17.1	V	V	V	V	693,604
KY	Kenton	15.9			V		151,464
LA	East Baton Rouge	14.6			V	V	412,852
LA	West Baton Rouge	14.1			V		21,601
MD	Baltimore	16			V		754,292
MD	Prince Georges	17.3	V	V	V	V	801,515
MD	Baltimore City	17.8	V	V	V	V	651,154
MA	Suffolk	16.1	V		V		689,807
MI	Wayne	18.9	V	V	V	V	2,061,162
MS	Jones	16.6	V		V	V	64,958
MO	St Louis City	16.3	V		V	V	348,189
MT	Lincoln	16.4	V	V	V	V	18,837
NJ	Hudson	17.5	V	V	V	V	608,975
NJ	Union	16.3			V	V	522,541
NY	Bronx	16.4	V		V	V	1,332,650
NY	New York	17.8	V	V	V	V	1,537,195
NC	Catawba	17.1	V		V	V	141,685
NC	Davidson	17.3	V	V	V	V	147,246
NC	Durham	15.3			V		223,314
NC	Forsyth	16.2			V	V	306,067
NC	Gaston	15.3			V		190,365
NC	Guilford	16.3	V		V	V	421,048
NC	McDowell	16.2			V		42,151
NC	Mecklenburg	16.8	V	V	V	V	695,454
NC	Wake	15.3			V		627,846
OH	Butler	17.4	V		V	V	332,807
OH	Cuyahoga	20.3	V	V	V	V	1,393,978
OH	Franklin	18.1	V	V	V	V	1,068,978
OH	Hamilton	19.3	V	V	V	V	845,303
OH	Jefferson	18.9	V	V	V	V	73,894
OH	Lawrence	17.4	V	V	V	V	62,319
OH	Lucas	16.7	V	V	V	V	455,054
OH	Mahoning	16.4			V		257,555
OH	Montgomery	17.6	V	V	V	V	559,062
OH	Scioto	20	V	V	V	V	79,195
OH	Stark	18.3	V	V	V	V	378,098
OH	Summit	17.3	V	V	V	V	542,899
OH	Trumbull	16.2			V		225,116

State	County	1999 - 2001 Design Value (ug/m^3)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
PA	Allegheny	21	V	V	V	V	1,281,666
PA	Delaware	15			V		550,864
PA	Philadelphia	16.6	V	V	V	V	1,517,550
PA	York	16.3			V		381,751
SC	Greenville	17	V	V	V	V	379,616
SC	Lexington	15.6			V		216,014
TN	Davidson	17			V	V	569,891
TN	Hamilton	18.9	V	V	V	V	307,896
TN	Knox	20.4	V	V	V	V	382,032
TN	Shelby	15.6			V		897,472
TN	Sullivan	17			V		153,048
TX	Dallas	14.4			V		2,218,899
TX	Harris	15.1	V	V	V	V	3,400,578
UT	Salt Lake	13.6			V		898,387
VA	Richmond City	14.9			V		197,790
WV	Brooke	17.4	V	V	V	V	25,447
WV	Cabell	17.8	V	V	V	V	96,784
WV	Hancock	17.4	V	V	V	V	32,667
WV	Kanawha	18.4	V	V	V	V	200,073
WV	Wood	17.6	V		V	V	87,986
WI	Milwaukee	14.5			V		940,164
Number of Violating Counties			79	67	107	84	
Population of Violating Counties[b]			65,821,078	60,453,470	85,525,624	71,375,639	

[a] The proposal differs based on updated information; however, we believe that the net results would approximate future emissions, although we anticipate the design value improvements would be slightly smaller.

[b] Populations are based on 2020 and 2030 estimates. See the AQ Modeling TSD for details.

Table 2.1.2-3 lists the counties with 2020 and 2030 projected annual $PM_{2.5}$ design values that do not violate the annual standard, but are within 10 percent of it. Counties are marked with an “X” in the table if their projected design values are greater than or equal to13.55 ug/m^3, but less than 15.05 ug/m^3. Counties are marked with an “V” in the table if their projected design values are greater than or equal to 15.05 ug/m^3. The current design values of these counties are also listed. These are counties that are not projected to violate the standard, but to be close to it, so the proposed rule will help assure that these counties continue to meet the standard.

Table 2.1.3-3
Counties with 2020 and 2030 Projected Annual PM2.5 Design Values within Ten Percent of the Annual PM2.5 Standard.[a]

State	County	1999 - 2001 Design Value (ug/m^3)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
AL	Alabama	15.5	X	X	X	X	14,254
AL	De Kalb	16.8	X	X	V	V	64,452
AL	Houston	16.3	V	X	V	V	88,787
AL	Madison	15.5			X		276,700
AL	Mobile	15.3	X	X	V	V	399,843
AR	Crittenden	15.3	X	X	X	X	50,866
AR	Pulaski	15.9	X	X	X	X	361,474
CA	Butte	15.4			X	X	203,171
CA	Imperial	15.7	X	X	V	X	142,361
CA	Kings	16.6	X		X	X	129,461
CA	San Joaquin	16.4	X	X	V	X	563,598
CA	Ventura	14.5	X	X	X	X	753,197
CT	Fairfield	13.6			X		882,567
DE	Sussex	14.5			X		156,638
GA	Hall	17.2	V	X	V	V	139,277
IL	Du Page	15.4	X	X	V	X	904,161
IL	Macon	15.4	X	X	X	X	114,706
IL	Will	15.9	V	X	V	V	502,266
IN	Elkhart	15.1	X		X	X	182,791
IN	Floyd	15.6	X	X	X	X	70,823
IN	Howard	15.4	X		X	X	84,964
IN	Marion	17	V	X	V	V	860,454
IN	Porter	13.9			X		146,798
IN	Tippecanoe	15.4	X		X	X	148,955
IN	Vanderburgh	16.9	X	X	V	X	171,922
KY	Bell	16.8	X	X	X	X	30,060
KY	Boyd	15.5	X	X	X	X	49,752
KY	Bullitt	16			X		61,236
KY	Campbell	15.5	X		X	X	88,616
KY	Daviess	15.8	X		X	X	91,545
KY	Fayette	16.8	X	X	X	X	260,512
KY	Kenton	15.9	X	X	V	X	151,464
KY	Pike	16.1	X	X	X	X	68,736
LA	Caddo	13.7			X	X	252,161
LA	Calcasieu	12.7			X		183,577
LA	East Baton Rouge	14.6	X	X	V	V	412,852
LA	Iberville	13.9	X		X	X	33,320
LA	Jefferson	13.6			X	X	455,466
LA	Orleans	14.1	X		X	X	484,674
LA	West Baton Rouge	14.1	X	X	V	X	21,601

State	County	1999 - 2001 Design Value (ug/m^3)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
MD	Baltimore	16	X	X	V	X	754,292
MA	Hampden	14.1			X		456,228
MA	Suffolk	16.1	V	X	V	X	689,807
MI	Kalamazoo	15	X		X	X	238,603
MS	Forrest	15.2	X	X	X	X	72,604
MS	Hinds	15.1	X		X	X	250,800
MS	Jackson	13.8			X	X	131,420
MS	Jones	16.6	V	X	V	V	64,958
MS	Lauderdale	15.3	X	X	X	X	78,161
MO	Jackson	13.9			X		654,880
MO	Jefferson	15	X	X	X	X	198,099
MO	St Charles	14.6	X		X	X	283,883
MO	St Louis	14.1			X		1,016,315
MO	St Louis City	16.3	V	X	V	V	348,189
NJ	Mercer	14.3	X		X	X	350,761
NJ	Union	16.3	X	X	V	V	522,541
NY	Bronx	16.4	V	X	V	V	1,332,650
NC	Alamance	15.3	X	X	X	X	130,800
NC	Cabarrus	15.7	X	X	X	X	131,063
NC	Catawba	17.1	V	X	V	V	141,685
NC	Cumberland	15.4	X		X	X	302,963
NC	Durham	15.3	X	X	V	X	223,314
NC	Forsyth	16.2	X	X	V	V	306,067
NC	Gaston	15.3	X	X	V	X	190,365
NC	Guilford	16.3	V	X	V	V	421,048
NC	Haywood	15.4	X		X	X	54,033
NC	McDowell	16.2	X	X	V	X	42,151
NC	Mitchell	15.5	X		X	X	15,687
NC	Orange	14.3			X		118,227
NC	Wake	15.3	X	X	V	X	627,846
NC	Wayne	15.3			X		113,329
OH	Butler	17.4	V	X	V	V	332,807
OH	Lorain	15.1	X		X	X	284,664
OH	Mahoning	16.4	X	X	V	X	257,555
OH	Portage	15.3	X	X	X	X	152,061
OH	Trumbull	16.2	X	X	V	X	225,116
PA	Berks	15.6	X	X	X	X	373,638
PA	Cambria	15.3			X		152,598
PA	Dauphin	15.5	X		X	X	251,798
PA	Delaware	15	X	X	V	X	550,864
PA	Lancaster	16.9	X	X	X	X	470,658
PA	Washington	15.5			X		202,897
PA	York	16.3	X	X	V	X	381,751

State	County	1999 - 2001 Design Value (ug/m^3)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
SC	Georgetown	13.9			X		55,797
SC	Lexington	15.6	X	X	V	X	216,014
SC	Richland	15.4	X	X	X	X	320,677
SC	Spartanburg	15.4	X	X	X	X	253,791
TN	Davidson	17	X	X	V	V	569,891
TN	Roane	17	X	X	X	X	51,910
TN	Shelby	15.6	X	X	V	X	897,472
TN	Sullivan	17	X	X	V	X	153,048
TN	Sumner	15.7	X		X	X	130,449
TX	Dallas	14.4	X	X	V	X	2,218,899
UT	Salt Lake	13.6	X		V	X	898,387
VA	Bristol City	16			X	X	17,367
VA	Richmond City	14.9	X	X	V	X	197,790
VA	Roanoke City	15.2			X		94,911
VA	Virginia Beach Cit	13.2			X		425,257
WV	Berkeley	16	X	X	X	X	75,905
WV	Marshall	16.5	X	X	X	X	35,519
WV	Ohio	15.7	X		X	X	47,427
WV	Wood	17.6	V	X	V	V	87,986
WI	Milwaukee	14.5	X	X	V	X	940,164
WI	Waukesha	14.1			X		360,767
Number of Counties within 10%			70	62	64	70	
Population of Counties within 10%[b]			23,836,367	24,151,782	16,870,324	24,839,565	

[a] The proposal differs based on updated information; however, we believe that the net results would approximate future emissions, although we anticipate the design value improvements would be slightly smaller.

[b] Populations are based on 2020 and 2030 estimates. See the AQ Modeling TSD for details.

We estimate that the reduction of this proposed rule would produce nationwide air quality improvements in PM levels. On a population weighted basis, the average change in future year annual averages would be a decrease of 0.33 ug/m^3 in 2020, and 0.46 ug/m^3 in 2030.

While the final implementation process for bringing the nation's air into attainment with the $PM_{2.5}$ NAAQS is still being completed in a separate rulemaking action, the basic framework is well defined by the statute. EPA's current plans call for designating $PM_{2.5}$ nonattainment areas in late-2004. Following designation, Section 172(b) of the Clean Air Act allows states up to 3 years to submit a revision to their state implementation plan (SIP) that provides for the attainment of the $PM_{2.5}$ standard. Based on this provision, states could submit these SIPs in late-2007. Section 172(a)(2) of the Clean Air Act requires that these SIP revisions demonstrate that the nonattainment areas will attain the $PM_{2.5}$ standard as expeditiously as practicable but no later than 5 years from the date that the area was designated nonattainment. However, based on the severity of the air quality problem and the availability and feasibility of control measures, the Administrator may extend the attainment date "for a period of no greater than 10 years from the date of designation as nonattainment." Therefore, based on this information, we expect that most or all areas will need to attain the $PM_{2.5}$ NAAQS in the 2009 to 2014 time frame, and then be required to maintain the NAAQS thereafter.

Since the emission reductions expected from today's proposal would begin in this same time frame, the projected reductions in nonroad emissions would be used by states in meeting the $PM_{2.5}$ NAAQS. States and state organizations have told EPA that they need nonroad diesel engine reductions in order to be able to meet and maintain the $PM_{2.5}$ NAAQS as well as visibility regulations, especially in light of the otherwise increasing emissions from nonroad sources without more stringent standards.[72, 73, 74] Furthermore, this action would ensure that nonroad diesel emissions will continue to decrease as the fleet turns over in the years beyond 2014; these reductions will be important for maintenance of the NAAQS following attainment. The future reductions are also important to achieve visibility goals, as discussed later.

2.1.3 Welfare Effects of Particulate Matter

In this section, we discuss public welfare effects of PM and its precursors including visibility impairment, acid deposition, eutrophication and nitrification, POM deposition, materials damage, and soiling.

2.1.3.1 Visibility Degradation

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[75] Visibility impairment has been considered the "best understood and most easily measured effect of air pollution."[76] Visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. Haze obscures the clarity, color, texture, and form of what we see. Fine particles are the major cause of reduced visibility in parts of the U.S. Visibility is an important effect because it has direct significance to people's enjoyment of daily activities in all parts of the country. Visibility is also highly valued in significant natural areas such as national parks and wilderness areas, because of the special emphasis given to protecting these lands now and for future generations.

Size and chemical composition of particles strongly affects their ability to scatter or absorb light. The same particles (sulfates, nitrates, organic carbon, smoke, and soil dust) comprising $PM_{2.5}$, which are linked to serious health effects and environmental effects (e.g., ecosystem damage), can also significantly degrade visual air quality. Sulfates contribute to visibility impairment especially on the haziest days across the U.S., accounting in the rural Eastern U.S. for more than 60 percent of annual average light extinction on the best days and up to 86 percent of average light extinction on the haziest days. Nitrates and elemental carbon each typically contribute 1 to 6 percent of average light extinction on haziest days in rural Eastern U.S. locations.[77]

To quantify changes in visibility, the analysis presented in this chapter computes a light-extinction coefficient, based on the work of Sisler, which shows the total fraction of light that is decreased per unit distance.[78] This coefficient accounts for the scattering and absorption of light by both particles and gases, and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Visibility can be described in terms of visual range, light extinction or deciview.[E] Visibility impairment also has a temporal dimension in that impairment might relate to a short-term excursion or to longer periods (e.g., worst 20 percent of days or annual average levels). More detailed discussions of visibility effects are contained in the EPA Criteria Document for PM.[79]

Visibility effects are manifest in two principal ways: (1) as local impairment (e.g., localized hazes and plumes) and (2) as regional haze. The emissions from engines covered by this rule contribute to both types of visibility impairment.

Local-scale visibility degradation is commonly in the form of either a plume resulting from the emissions of a specific source or small group of sources, or it is in the form of a localized haze such as an urban “brown cloud.” Plumes are comprised of smoke, dust, or colored gas that obscure the sky or horizon relatively near sources. Impairment caused by a specific source or small group of sources has been generally termed as “reasonably attributable.”

The second type of impairment, regional haze, results from pollutant emissions from a multitude of sources located across a broad geographic region. It impairs visibility in every direction over a large area, in some cases over multi-state regions. Regional haze masks objects on the horizon and reduces the color and contrast of nearby objects.[80]

On an annual average basis, the concentrations of non-anthropogenic fine PM are generally small when compared with concentrations of fine particles from anthropogenic sources.[81] Anthropogenic contributions account for about one-third of the average extinction coefficient in the rural West and more than 80 percent in the rural East.[82] In the Eastern U.S., reduced visibility is mainly attributable to secondarily formed particles, particularly those less than a few micrometers in diameter (e.g., sulfates). While secondarily formed particles still account for a significant amount in the West, primary emissions contribute a larger percentage of the total particulate load than in the East. Because of significant differences related to visibility conditions in the Eastern and Western U.S., we present information about visibility by region. Furthermore, it is important to note that even in those areas with relatively low concentrations of anthropogenic fine particles, such as the Colorado plateau, small increases in anthropogenic fine particle concentrations can lead to significant decreases in visual range. This is one of the

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[E] Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. It is typically described in miles or kilometers. Light extinction is the sum of light scattering and absorption by particles and gases in the atmosphere. It is typically expressed in terms of inverse megameters (Mm^{-1}), with larger values representing worse visibility. The deciview metric describes perceived visual changes in a linear fashion over its entire range, analogous to the decibel scale for sound. A deciview of 0 represents pristine conditions. The higher the deciview value, the worse the visibility, and an improvement in visibility is a decrease in deciview value.

reasons mandatory Federal Class I areas have been given special consideration under the Clean Air Act. The 156 mandatory Federal Class I areas are displayed on the map in Figure 2-1 above.

EPA determined that emissions from nonroad engines significantly contribute to air pollution which may be reasonably anticipated to endanger public health and welfare for visibility effects in particular (67 FR 68242, November 8, 2002). The primary and PM-precursor emissions from nonroad diesel engines subject to this proposed rule contribute to these effects. To demonstrate this, in addition to the inventory information in Chapter 3, we present information about both general visibility impairment related to ambient PM levels across the country, and we also analyze visibility conditions in mandatory Federal Class I areas. Accordingly, in this section, for both the nation and mandatory Federal Class I areas, we discuss the types of effects, current and future visibility conditions absent the proposed reductions, and the changes we anticipate from the proposed reductions in emissions from nonroad diesels. We conclude that the proposed reductions will improve visibility conditions across the country and in particular in mandatory Federal Class I areas.

2.1.3.1.1 Visibility Impairment Where People Live, Work and Recreate

Good visibility is valued by people throughout the country - in the places they live, work, and enjoy recreational activities. However, unacceptable visibility impairment occurs in many areas throughout the country. In this section, in order to estimate the magnitude of the visibility problem, we use monitored $PM_{2.5}$ data and modeled air quality accounting for projected emissions from nonroad diesel engines absent additional controls. The air quality modeling is discussed in Section 2.1.2 above and in the AQ Modeling TSD.[83] The engines covered by this rule contribute to $PM_{2.5}$ levels in areas across the country with significant visibility impairment.

The secondary PM NAAQS is designed to protect against adverse welfare effects such as visibility impairment. In 1997, the secondary PM NAAQS was set as equal to the primary (health-based) PM NAAQS (62 Federal Register No. 138, July 18, 1997). EPA concluded that PM can and does produce adverse effects on visibility in various locations, depending on PM concentrations and factors such as chemical composition and average relative humidity. In 1997, EPA demonstrated that visibility impairment is an important effect on public welfare and that visibility impairment is experienced throughout the U.S., in multi-state regions, urban areas, and remote Federal Class I areas.

The updated monitored data and air quality modeling presented below confirm that the visibility situation identified during the NAAQS review in 1997 is still likely to exist. Specifically, there will still likely be a broad number of areas that are above the annual $PM_{2.5}$ NAAQS in the Northeast, Midwest, Southeast and California , such that the determination in the NAAQS rulemaking about broad visibility impairment and related benefits from NAAQS compliance are still relevant. Thus, levels above the fine PM NAAQS cause adverse welfare impacts, such as visibility impairment (both regional and localized impairment). EPA recently confirmed this in our determination about nonroad engines significant contribution to unacceptable visibility impairment (67 FR 68251, November 8, 2002).

In addition, in setting the PM NAAQS, EPA acknowledged that levels of fine particles below the NAAQS may also contribute to unacceptable visibility impairment and regional haze problems in some areas, and Clean Air Act Section 169 provides additional authorities to remedy existing impairment and prevent future impairment in the 156 national parks, forests and wilderness areas labeled as mandatory Federal Class I areas (62 FR at 38680-81, July 18, 1997).

In making determinations about the level of protection afforded by the secondary PM NAAQS, EPA considered how the Section 169 regional haze program and the secondary NAAQS would function together.[84] Regional strategies are expected to improve visibility in many urban and non-Class I areas as well. Visibility impairment in mandatory Federal Class I areas is discussed in Section 2.1.4.

2.1.3.1.1.1 Current Areas Affected by Visibility Impairment: Monitored Data

The need for reductions in the levels of $PM_{2.5}$ is widespread, as discussed above and shown in Figure 2-1. Currently, high ambient $PM_{2.5}$ levels are measured throughout the country. Fine particles may remain suspended for days or weeks and travel hundreds to thousands of kilometers, and thus fine particles emitted or created in one county may contribute to ambient concentrations in a neighboring region.[85]

Without the effects of pollution, a natural visual range is approximately 140 miles (230 kilometers) in the West and 90 miles (150 kilometers) in the East. However, over the years, in many parts of the U.S., fine particles have significantly reduced the range that people can see. In the West, the current range is 33 to 90 miles (53 to 144 kilometers), and in the East, the current range is only 14 to 24 miles (22 to 38 kilometers).[86]

Current $PM_{2.5}$ monitored values for 1999-2001 indicate that at least 65 million people in 129 counties live in areas where design values of $PM_{2.5}$ annual levels are at or above the $PM_{2.5}$ NAAQS. There are an additional 9 million people in 20 counties where levels exceeding the NAAQS are being measured, but there are insufficient data at this time to make a complete comparison with the NAAQS. In total, this represents 37 percent of the counties and 64 percent of the population in the areas with monitors with levels above the NAAQS. Taken together, these data indicate that a total of 74 million people live in areas where long-term ambient fine particulate matter levels are at or above 15 $\mu g/m^3$.[87] Thus, at least these populations (plus others who travel to these areas) would likely be experiencing visibility impairment that is unacceptable. Emissions of PM and its precursors from nonroad diesel engines contribute to this unacceptable impairment.

An additional 14 million people live in 41 counties that have air quality measurements for 1999-2001 within 10 percent of the level of the PM standard. These areas, although not currently violating the standard, would also benefit from the additional reductions from this proposed rule in order to ensure long term maintenance of the standard and to prevent deterioration in visibility conditions.

Although we present the annual average to represent national visibility conditions, visibility impairment can also occur on certain days or other shorter periods. As discussed below, the Regional Haze program targets the worst 20 percent of days in a year. The reductions from this proposed rule are also needed to improve visibility on the worst days.

2.1.3.1.1.2 Areas Affected by Future Visibility Impairment

Because the chemical composition of PM and other atmospheric conditions affect visibility impairment, we used the REMSAD air quality model to project visibility conditions in 2020 and 2030 to estimate visibility impairment directly as changes in deciview. One of the inputs to the PM modeling described above is a projection of future emissions from nonroad diesel engines absent additional controls. Thus, we are able to demonstrate that the nonroad diesel emissions contribute to the projected visibility impairment and that there continues to be a need for reductions from those engines.

As described above, based on this modeling and absent additional controls, we predicted that in 2020, there will be 79 counties with a population of 66 million where annual $PM_{2.5}$ levels are above 15 µg/m3.[88] In 2030, this number will rise to 107 counties with a population of 71 million in the absence of additional controls. Section 2.1.2 and the AQ Modeling TSD provides additional details.

Based upon the light-extinction coefficient, we also calculated a unitless visibility index or deciview. As shown in Table 2.1.3-1, in 2030 we estimate visibility in the East to be about 20.54 deciviews (or visual range of 50 kilometers) on average, with poorer visibility in urban areas, compared to the visibility conditions without man-made pollution of 9.5 deciviews (or visual range of 150 kilometers). Likewise, we estimate visibility in the West to be about 8.83 deciviews (or visual range of 162 kilometers) in 2030, compared to the visibility conditions without anthropogenic pollution of 5.3 deciviews (or visual range of 230 kilometers). Thus, in the future, a substantial percent of the population may experience unacceptable visibility impairment in areas where they live, work and recreate.

Table 2.1.3-1
Summary of Future National (48 state) Baseline Visibility
Conditions Absent Additional Controls (Deciviews)

Regions[a]	Predicted 2020 Visibility (annual average)	Predicted 2030 Visibility (annual average)	Natural Background Visibility
Eastern U.S.	20.27	20.54	9.5
Urban	21.61	21.94	
Rural	19.73	19.98	
Western U.S.	8.69	8.83	5.3
Urban	9.55	9.78	
Rural	8.5	8.61	

[a] Eastern and Western Regions are separated by 100 degrees north longitude. Background visibility conditions differ by region.

The emissions from nonroad diesel engines contribute to this visibility impairment as discussed in Chapter 3. Nonroad diesel engines emissions contribute a large portion of the total PM emissions from mobile sources and anthropogenic sources, in general. These emissions occur in and around areas with PM levels above the annual $PM_{2.5}$ NAAQS. The nonroad engines subject to this proposed rule contribute to these effects. Thus, the emissions from these sources contribute to the unacceptable current and anticipated visibility impairment.

2.1.3.1.1.3 Future Improvements in Visibility from the Proposed Reductions

For this proposal, we also modeled a preliminary control scenario which illustrates the likely reductions from our proposal. Because of the substantial lead time to prepare the complex air quality modeling analyses, it was necessary to develop a control options early in the process based on our best judgement at that time. As additional data regarding technical feasibility and other factors became available, our judgement about the controls that are feasible has evolved. Thus, the preliminary control option differs from what we are proposing, as summarized in Section 3.6 below. It is important to note that these changes would not affect our estimates of the baseline conditions without additional controls described above. For the final rule, considering public comment, we plan to model the final control scenario. We anticipate that the proposed nonroad diesel emissions reductions would improve to the projected visibility impairment, and that there continues to be a need for reductions from those engines.

Based on our modeling, we predict that in 2020, there would be 12 counties with a population of 6 million that would come into attainment with the annual $PM_{2.5}$ because of the improvements in air quality from the proposed emissions reductions. In 2030, a total of 24 counties (12 additional counties) with a population of 14 million (8 million additional people) would come into attainment with the annual $PM_{2.5}$ because of the improvements in air quality from the proposed emissions reductions. There would also be reductions in counties with levels close to the standard that would improve visibility conditions and help them maintain the standards. All of these areas and their populations would experience improvements in visibility as well as health, described earlier.

We estimate that the reduction of this proposed rule would produce nationwide air quality improvements in PM levels. On a population weighted basis, the average change in future year annual averages would be a decrease of 0.33 ug/m^3 in 2020, and 0.46 ug/m^3 in 2030. These reductions are discussed in more detail in Section 2.1.2 above.

We can also calculate these improvement in visibility as decreases in deciview value. As shown in Table 2.1.3-2, in 2030 we estimate visibility in the East to be about 20.54 deciviews (or visual range of 50 kilometers) on average, with poorer visibility in urban areas. Emission reductions from this proposed rule in 2030 would improve visibility by 0.33 deciview. Likewise, we estimate visibility in the West to be about 8.83 deciviews (or visual range of 162 kilometers) in 2030, and we estimate emission reductions from this proposed rule in 2030 would improve visibility by 0.25 deciview. These improvements are needed in conjunction with other sulfur strategies in the East and a combination of strategies in the West to make reasonable progress toward visibility goals.[89] Thus, in the future, a substantial percent of the population may experience improvements visibility in areas where they live, work and recreate because of the proposed nonroad emission reductions.

Table 2.1.3-2
Summary of Future National Visibility Improvements
from Nonroad Diesel Emission Reductions (Annual Average Deciviews)

Regions[a]	2020		2030	
	Predicted Baseline 2020 Visibility	Predicted 2020 Control Visibility[b]	Predicted Baseline 2030 Visibility	Predicted 2030 Control Visibility[b]
Eastern U.S.	20.27	20.03	20.54	20.21
Urban	21.61	21.37	21.94	21.61
Rural	19.73	19.49	19.98	19.65
Western U.S.	8.69	8.51	8.83	8.58
Urban	9.55	9.3	9.78	9.43
Rural	8.5	8.33	8.61	8.38

[a] Eastern and Western Regions are separated by 100 degrees north longitude. Background visibility conditions differ by region.
[b] The results illustrate the type of visibility improvements for the preliminary control option, as discussed in Section 3.6. The proposal differs based on updated information; however, we believe that the net results would approximate future PM emissions, although we anticipate the visibility improvements would be slightly smaller.

2.1.3.1.2 Visibility Impairment in Mandatory Federal Class I Areas

Achieving the annual $PM_{2.5}$ NAAQS will help improve visibility across the country, but it will not be sufficient to meet the statutory goal of no manmade impairment in the mandatory Federal Class I areas (64 FR 35722, July 1, 1999 and 62 FR 38680, July 18, 1997). In setting the NAAQS, EPA discussed how the NAAQS in combination with the regional haze program, is deemed to improve visibility consistent with the goals of the Act.[90] In the East, there are and will continue to be sizable areas above 15 ug/m^3 and where light extinction is significantly above natural background. Thus, large areas of the Eastern U.S. have air pollution that is causing and will continue to cause unacceptable visibility problems. In the West, scenic vistas are especially important to public welfare. Although the annual $PM_{2.5}$ NAAQS is met in most areas outside of California, virtually the entire West is in close proximity to a scenic mandatory Federal Class I area protected by 169A and 169B of the Act.

The 156 Mandatory Federal Class I areas are displayed on the map in Figure 2-1 above. These areas include many of our best known and most treasured natural areas, such as the Grand Canyon, Yosemite, Yellowstone, Mount Rainier, Shenandoah, the Great Smokies, Acadia, and the Everglades. More than 280 million visitors come to enjoy the scenic vistas and unique natural features in these and other park and wilderness areas each year.

In the 1990 Clean Air Act amendments, Congress provided additional emphasis on regional haze issues (see section 169B). In 1999 EPA finalized a rule that calls for States to establish goals and emission reduction strategies for improving visibility in all 156 mandatory Class I national parks and wilderness areas. In this rule, EPA established a "natural visibility" goal.[91] In that rule, EPA also encouraged the States to work together in developing and implementing their air quality plans. The regional haze program is focused on long-term emissions decreases from the entire regional emissions inventory comprised of major and minor stationary sources, area sources and mobile sources. The regional haze program is designed to improve visibility and air quality in our most treasured natural areas so that these areas may be preserved and enjoyed by current and future generations. At the same time, control strategies designed to improve visibility in the national parks and wilderness areas will improve visibility over broad geographic areas, including other recreational sites, our cities and residences. In the PM NAAQS rulemaking, EPA also anticipated the need in addition to the NAAQS and Section 169 regional haze program to continue to address localized impairment that may relate to unique circumstances in some Western areas. For mobile sources, there may also be a need for a Federal role in reduction of those emissions, in particular, because mobile source engines are regulated primarily at the Federal level.

The regional haze program calls for states to establish goals for improving visibility in national parks and wilderness areas to improve visibility on the haziest 20 percent of days and to ensure that no degradation occurs on the clearest 20 percent of days (64 FR 35722. July 1, 1999). The rule requires states to develop long-term strategies including enforceable measures designed to meet reasonable progress goals toward natural visibility conditions. Under the regional haze program, States can take credit for improvements in air quality achieved as a result of other Clean Air Act programs, including national mobile-source programs.[F]

2.1.3.1.2.1 Current Mandatory Federal Class I Areas Affected by Visibility Impairment: Monitored Data

Detailed information about current and historical visibility conditions in mandatory Federal Class I areas is summarized in the EPA Report to Congress and the recent EPA Trends Report.[92] The conclusions draw upon the Interagency Monitoring of Protected Visual Environments (IMPROVE) network data.[93]

As described in the EPA Trends Report, most of the IMPROVE sites in the intermountain West and Colorado Plateau have annual average impairment of 12 deciviews or less, with the

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[F] Although a recent court case, American Corn Growers Association v. EPA, 291F.3d 1(D.C .Cir 2002), vacated the Best Available Retrofit Technology (BART) provisions of the Regional Haze rule, the court denied industry's challenge to EPA's requirement that state's SIPS provide for reasonable progress towards achieving natural visibility conditions in national parks and wilderness areas and the "no degradation" requirement. Industry did not challenge requirements to improve visibility on the haziest 20 percent of days. The court recognized that mobile source emission reductions would need to be a part of a long-term emission strategy for reducing regional haze. A copy of this decision can be found in Docket A-2000-01, Document IV- A-113.

worst days ranging up to 17 deciviews (compared to 5.3 deciviews of natural background visibility).[94] Several other western IMPROVE sites in the Northwest and California experience levels on the order of 16 to 23 deciviews on the haziest 20 percent of days. Many rural locations in the East have annual average values exceeding 21 deciviews, with average visibility levels on the haziest days up to 32 deciviews.

Although there have been general trends toward improved visibility, progress is still needed on the haziest days. Specifically, as discussed in the EPA Trends Report, in the 10 Eastern U.S. Class I areas trend sites, visibility on the haziest 20 percent of days remains significantly impaired with a mean visual range of 23 kilometers for 1999 as compared to 84 kilometers for the clearest days in 1999. In the 26 Western U.S. Class I areas trends sites, the conditions for the haziest 20 percent of days degraded between 1997 and 1999 by 17 percent. However, visibility on the haziest 20 percent of days in the West remains relatively unchanged over the 1990s with the mean visual range for 1990 (80 kilometers) nearly the same as the 1990 level (86 kilometers).

2.1.3.1.2.2 Mandatory Federal Class I Areas Affected by Future Visibility Impairment

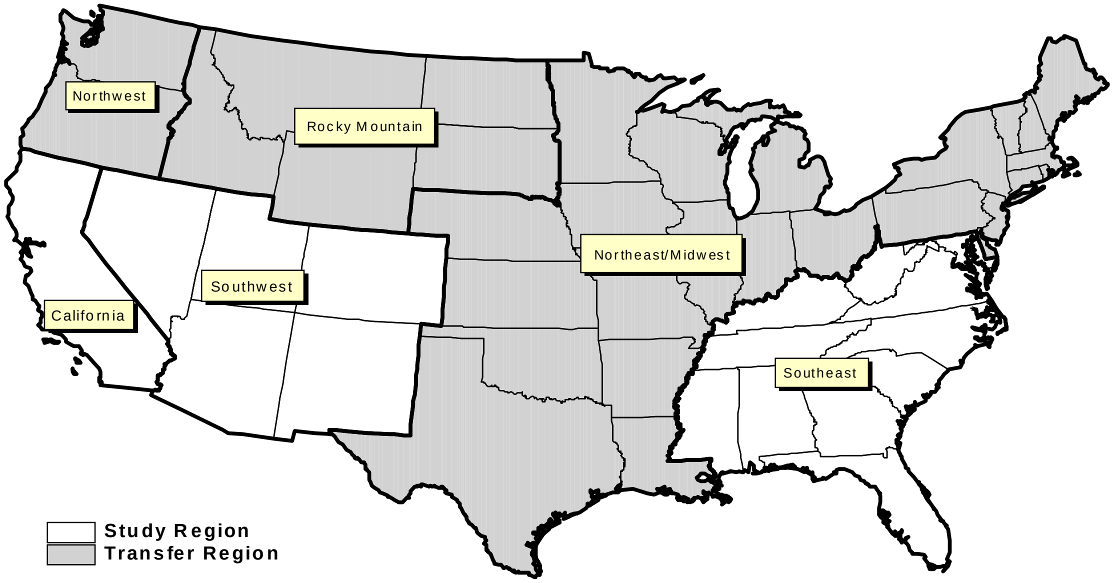
As part of the PM air quality modeling described above, we modeled future visibility conditions in the mandatory Federal Class I areas absent additional controls. The results by region are summarized in Table 2.1.3-3. In Figure 2.1.3-1, we define the regions used in this analysis.[95] These air quality results show that visibility is impaired in most mandatory Federal Class I areas and additional reductions from engines subject to this rule are needed to achieve the goals of the Clean Air Act of preserving natural conditions in mandatory Federal Class I areas.

Table 2.1.3-3
Summary of Future Baseline Visibility Conditions in Mandatory Federal Class I Areas Absent Additional Emissions Reductions (Annual Average Deciview)

Class I Regions [a]	Predicted 2020 Visibility	Predicted 2030 Visibility	Natural Background Visibility
Eastern	19.72	20.01	9.5
Southeast	21.31	21.62	
Northeast/Midwest	18.30	18.56	
Western	8.80	8.96	5.3
Southwest	6.87	7.03	
California	9.33	9.56	
Rocky Mountain	8.46	8.55	
Northwest	12.05	12.18	
National Class I Area Average	11.61	11.80	

[a] Regions are depicted in Figure 1-5.1. Background visibility conditions differ by region based on differences in relative humidity and other factors: Eastern natural background is 9.5 deciviews (or visual range of 150 kilometers) and in the West natural background is 5.3 deciviews (or visual range of 230 kilometers).

Figure 2.1.3-1
Visibility Regions for Continental U.S.



Note: Study regions were represented in the Chestnut and Rowe (1990a, 1990b) studies used in evaluating the benefits of visibility improvements.

2.1.3.1.2.3 Future Improvements in Mandatory Federal Class I Visibility from the Proposed Reductions

The overall goal of the regional haze program is to prevent future and remedy existing visibility impairment in mandatory Federal Class I areas. As shown by the future deciview estimates in Table 2.1.3-4, additional emissions reductions will be needed from the broad set of sources that contribute, including the emissions from engines subject to this rule. The table also presents the results from our modeling of a preliminary control scenario which illustrates the likely reductions from our proposal. Emission reductions from nonroad diesel engines are needed to achieve the goals of the Act of preserving natural conditions in mandatory Federal Class I areas. These reductions are a part of the overall strategy to achieve the visibility goals of the Act and the regional haze program.

Table 2.1.3-4
Summary of Future Visibility Improvements[b] in Mandatory Federal Class I Areas from Nonroad Diesel Emission Reductions (Annual Average Deciviews)

Mandatory Federal Class I Regions[a]	2020		2030	
	Predicted Baseline 2020 Average Visibility	Predicted 2020 Control Average Visibility[b]	Predicted Baseline 2030 Average Visibility	Predicted 2030 Control Average Visibility[b]
Eastern	19.72	19.54	20.01	19.77
Southeast	21.31	21.13	21.62	21.38
Northeast/Midwest	18.30	18.12	18.56	18.32
Western	8.80	8.62	8.96	8.72
Southwest	6.87	6.71	7.03	6.82
California	9.33	9.12	9.56	9.26
Rocky Mountain	8.46	8.31	8.55	8.34
Northwest	12.05	11.87	12.18	11.94
National Class I Area Average	11.61	11.43	11.80	11.56

[a] Regions are presented in Figure 2.1.3-1 based on Chestnut and Rowe (1990a, 1990b) study regions.

[b] The results illustrate the type of visibility improvements for the preliminary control option, as discussed in Section 3.6. The proposal differs based on updated information; however, we believe that the net results would approximate future PM emissions, although we anticipate the visibility improvements would be slightly smaller.

2.1.3.2 Other Effects

2.1.3.2.1 Acid Deposition

Acid deposition, or acid rain as it is commonly known, occurs when SO_2 and NOx react in the atmosphere with water, oxygen, and oxidants to form various acidic compounds that later fall to earth in the form of precipitation or dry deposition of acidic particles.[96] It contributes to damage of trees at high elevations and in extreme cases may cause lakes and streams to become so acidic that they cannot support aquatic life. In addition, acid deposition accelerates the decay of building materials and paints, including irreplaceable buildings, statues, and sculptures that are part of our nation's cultural heritage. To reduce damage to automotive paint caused by acid rain and acidic dry deposition, some manufacturers use acid-resistant paints, at an average cost of $5 per vehicle—a total of near $80 million per year when applied to all new cars and trucks sold in the U.S. each year.

Acid deposition primarily affects bodies of water that rest atop soil with a limited ability to neutralize acidic compounds. The National Surface Water Survey (NSWS) investigated the effects of acidic deposition in over 1,000 lakes larger than 10 acres and in thousands of miles of streams. It found that acid deposition was the primary cause of acidity in 75 percent of the acidic lakes and about 50 percent of the acidic streams, and that the areas most sensitive to acid rain were the Adirondacks, the mid-Appalachian highlands, the upper Midwest and the high elevation West. The NSWS found that approximately 580 streams in the Mid-Atlantic Coastal Plain are acidic primarily due to acidic deposition. Hundreds of the lakes in the Adirondacks surveyed in the NSWS have acidity levels incompatible with the survival of sensitive fish species. Many of the over 1,350 acidic streams in the Mid-Atlantic Highlands (mid-Appalachia) region have already experienced trout losses due to increased stream acidity. Emissions from U.S. sources contribute to acidic deposition in eastern Canada, where the Canadian government has estimated that 14,000 lakes are acidic. Acid deposition also has been implicated in contributing to degradation of high-elevation spruce forests that populate the ridges of the Appalachian Mountains from Maine to Georgia. This area includes national parks such as the Shenandoah and Great Smoky Mountain National Parks.

A study of emissions trends and acidity of water bodies in the Eastern U.S. by the General Accounting Office (GAO) found that from 1992 to 1999 sulfates declined in 92 percent of a representative sample of lakes, and nitrate levels increased in 48 percent of the lakes sampled.[97] The decrease in sulfates is consistent with emissions trends, but the increase in nitrates is inconsistent with the stable levels of nitrogen emissions and deposition. The study suggests that the vegetation and land surrounding these lakes have lost some of their previous capacity to use nitrogen, thus allowing more of the nitrogen to flow into the lakes and increase their acidity. Recovery of acidified lakes is expected to take a number of years, even where soil and vegetation have not been "nitrogen saturated," as EPA called the phenomenon in a 1995 study.[98] This situation places a premium on reductions of SOx and especially NOx from all sources, including nonroad diesel engines, in order to reduce the extent and severity of nitrogen saturation and acidification of lakes in the Adirondacks and throughout the U.S.

The SOx and NOx reductions from today's action will help reduce acid rain and acid deposition, thereby helping to reduce acidity levels in lakes and streams throughout the country and help accelerate the recovery of acidified lakes and streams and the revival of ecosystems adversely affected by acid deposition. Reduced acid deposition levels will also help reduce stress on forests, thereby accelerating reforestation efforts and improving timber production. Deterioration of our historic buildings and monuments, and of buildings, vehicles, and other structures exposed to acid rain and dry acid deposition also will be reduced, and the costs borne to prevent acid-related damage may also decline. While the reduction in sulfur and nitrogen acid deposition will be roughly proportional to the reduction in SOx and NOx emissions, respectively, the precise impact of today's action will differ across different areas.

2.1.3.2.2 Eutrophication and Nitrification

Eutrophication is the accelerated production of organic matter, particularly algae, in a water body. This increased growth can cause numerous adverse ecological effects and economic impacts, including nuisance algal blooms, dieback of underwater plants due to reduced light penetration, and toxic plankton blooms. Algal and plankton blooms can also reduce the level of dissolved oxygen, which can also adversely affect fish and shellfish populations.

In 1999, the National Oceanic and Atmospheric Administration (NOAA) published the results of a five year national assessment of the severity and extent of estuarine eutrophication. An estuary is defined as the inland arm of the sea that meets the mouth of a river. The 138 estuaries characterized in the study represent more than 90 percent of total estuarine water surface area and the total number of US estuaries. The study found that estuaries with moderate to high eutrophication conditions represented 65 percent of the estuarine surface area. Eutrophication is of particular concern in coastal areas with poor or stratified circulation patterns, such as the Chesapeake Bay, Long Island Sound, or the Gulf of Mexico. In such areas, the "overproduced" algae tends to sink to the bottom and decay, using all or most of the available oxygen and thereby reducing or eliminating populations of bottom-feeder fish and shellfish, distorting the normal population balance between different aquatic organisms, and in extreme cases causing dramatic fish kills.

Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation’s fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algal blooms create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation. According to the NOAA report, more than half of the nation’s estuaries have moderate to high expressions of at least one of these symptoms – an indication that eutrophication is well developed in more than half of U.S. estuaries.

In recent decades, human activities have greatly accelerated nutrient inputs, such as nitrogen and phosphorous, causing excessive growth of algae and leading to degraded water quality and associated impairments of freshwater and estuarine resources for human uses.[99] Since 1970, eutrophic conditions worsened in 48 estuaries and improved in 14. In 26 systems, there was no trend in overall eutrophication conditions since 1970. [100] On the New England coast, for example, the number of red and brown tides and shellfish problems from nuisance and toxic plankton blooms have increased over the past two decades, a development thought to be linked to increased nitrogen loadings in coastal waters. Long-term monitoring in the U.S., Europe, and other developed regions of the world shows a substantial rise of nitrogen levels in surface waters, which are highly correlated with human-generated inputs of nitrogen to their watersheds.

Between 1992 and 1997, experts surveyed by National Oceanic and Atmospheric Administration (NOAA) most frequently recommended that control strategies be developed for agriculture, wastewater treatment, urban runoff, and atmospheric deposition.[101] In its Third Report to Congress on the Great Waters, EPA reported that atmospheric deposition contributes from 2 to 38 percent of the nitrogen load to certain coastal waters.[102] A review of peer reviewed literature in 1995 on the subject of air deposition suggests a typical contribution of 20 percent or higher.[103] Human-caused nitrogen loading to the Long Island Sound from the atmosphere was estimated at 14 percent by a collaboration of federal and state air and water agencies in 1997.[104] The National Exposure Research Laboratory, US EPA, estimated based on prior studies that 20 to 35 percent of the nitrogen loading to the Chesapeake Bay is attributable to atmospheric deposition.[105] The mobile source portion of atmospheric NOx contribution to the Chesapeake Bay was modeled at about 30 percent of total air deposition.[106]

Deposition of nitrogen from nonroad diesel engines contributes to elevated nitrogen levels in waterbodies. The proposed standards for nonroad diesel engines will reduce total NOx emissions by 831,000 tons in 2030. The NOx reductions will reduce the airborne nitrogen deposition that contributes to eutrophication of watersheds, particularly in aquatic systems where atmospheric deposition of nitrogen represents a significant portion of total nitrogen loadings.

2.1.3.2.3 Polycyclic Organic Matter (POM) Deposition

EPA's Great Waters Program has identified 15 pollutants whose deposition to water bodies has contributed to the overall contamination loadings to the these Great Waters.[107] One of these 15 compounds, a group known as polycyclic organic matter (POM), are compounds that are mainly adhered to the particles emitted by mobile sources and later fall to earth in the form of precipitation or dry deposition of particles. The mobile source contribution of the 7 most toxic POM is at least 62 tons/year[108] and represents only those POM that are adhered to mobile source particulate emissions. The majority of these emissions are produced by diesel engines.

POM is generally defined as a large class of chemicals consisting of organic compounds having multiple benzene rings and a boiling point greater than 100° C. Polycyclic aromatic hydrocarbons are a chemical class that is a subset of POM. POM are naturally occurring substances that are byproducts of the incomplete combustion of fossil fuels and plant and animal biomass (e.g., forest fires). Also, they occur as byproducts from steel and coke productions and waste incineration.

Evidence for potential human health effects associated with POM comes from studies in animals (fish, amphibians, rats) and in human cells culture assays. Reproductive, developmental, immunological, and endocrine (hormone) effects have been documented in these systems. Many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data.

The PM reductions from today's proposed action will help reduce not only the PM emissions from land-based nonroad diesel engines but also the deposition of the POM adhering to the particles, thereby helping to reduce health effects of POM in lakes and streams, accelerate the recovery of affected lakes and streams, and revive the ecosystems adversely affected.

2.1.3.2.4 Materials Damage and Soiling

The deposition of airborne particles can also reduce the aesthetic appeal of buildings and culturally important articles through soiling, and can contribute directly (or in conjunction with other pollutants) to structural damage by means of corrosion or erosion. Particles affect materials principally by promoting and accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Particles contribute to these effects because of their electrolytic, hygroscopic, and acidic properties, and their ability to sorb corrosive gases (principally sulfur dioxide). The rate of metal corrosion depends on a number of factors, including the deposition rate and nature of the pollutant; the influence of the metal protective corrosion film; the amount of moisture present; variability in the electrochemical reactions; the presence and concentration of other surface electrolytes; and the orientation of the metal surface.

Paints undergo natural weathering processes from exposure to environmental factors such as sunlight, moisture, fungi, and varying temperatures. In addition to the natural environmental factors, studies show particulate matter exposure may give painted surfaces a dirty appearance. Several studies also suggest that particles serve as carriers of other more corrosive pollutants, allowing the pollutants to reach the underlying surface or serve as concentration sites for other pollutants. A number of studies have shown some correlation between particulate matter and damage to automobile finishes. A number of studies also support the conclusion that gaseous pollutants contribute to the erosion rates of exterior paints.

Damage to calcareous stones (i.e., limestone, marble and carbonated cemented stone) has been attributed to deposition of acidic particles. Moisture and salts are considered the most important factors in building material damage. However, many other factors (such as normal weathering and microorganism damage) also seem to play a part in the deterioration of inorganic building materials. The relative importance of biological, chemical, and physical mechanisms has not been studied to date. Thus, the relative contribution of ambient pollutants to the damage observed in various building stone is not well quantified. Under high wind conditions, particulates result in slow erosion of the surfaces, similar to sandblasting.

Soiling is the accumulation of particles on the surface of an exposed material resulting in the degradation of its appearance. When such accumulation produces sufficient changes in reflection from opaque surfaces and reduces light transmission through transparent materials, the surface will become perceptibly dirty to the human observer. Soiling can be remedied by cleaning or washing, and depending on the soiled material, repainting.

2.2 Air Toxics

2.2.1 Diesel Exhaust PM

A number of health studies have been conducted regarding diesel exhaust including epidemiologic studies of lung cancer in groups of workers, and animal studies focusing on non-cancer effects specific to diesel exhaust. Diesel exhaust PM (including the associated organic compounds which are generally high molecular weight hydrocarbon types but not the more volatile gaseous hydrocarbon compounds) is generally used as a surrogate measure for diesel exhaust.

2.2.1.1 Potential Cancer Effects of Diesel Exhaust

In addition to its contribution to ambient PM inventories, diesel exhaust is of specific concern because it has been judged to pose a lung cancer hazard for humans as well as a hazard from noncancer respiratory effects such as pulmonary inflammation.

In 2001, EPA completed a rulemaking on mobile source air toxics with a determination that diesel particulate matter and diesel exhaust organic gases be identified as a Mobile Source Air Toxic (MSAT).[109] This determination was based on a draft of the Diesel HAD on which the Clean Air Scientific Advisory Committee (CASAC) of the Science Advisory Board had reached closure. Including both diesel PM and diesel exhaust organic gases in the determination was made in order to be precise about the components of diesel exhaust expected to contribute to the observed cancer and non-cancer health effects. Currently available science, while suggesting an important role for the particulate phase component of diesel exhaust, does not attribute the likely cancer and noncancer health effects independently to diesel particulate matter as distinct from the gas phase components (EPA, 2001). The purpose of the MSAT list is to provide a screening tool that identifies compounds emitted from motor vehicles or their fuels for which further evaluation of emissions controls is appropriate.

EPA recently released its final “Health Assessment Document for Diesel Engine Exhaust”, (the EPA Diesel HAD), referenced earlier. There, diesel exhaust was classified as likely to be carcinogenic to humans by inhalation at environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines.[110] In accordance with earlier EPA guidelines, diesel exhaust would be similarly classified as a probable human carcinogen (Group B1).[111, 112] A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the US Department of Health and Human Services) have made similar classifications.[113,114,115,116,117] The Health Effects Institute has also made numerous studies and report on the potential carcinogenicity of diesel exhaust.[118, 119, 120] Numerous animal and bioassay/genotoxic tests have been done on diesel exhaust.[121, 122] Also, case-control and cohort studies have been conducted on railroad engine exposures[123,124,125] in addition to studies on truck workers. [126, 127,128] Also, there are numerous other epidemiologic studies including some studying mine workers and fire fighters.[129, 130]

It should be noted that the conclusions in the EPA Diesel HAD were based on diesel engines currently in use, including nonroad diesel engines such as those found in bulldozers, graders, excavators, farm tractor drivers and heavy construction equipment. As new diesel engines with significantly cleaner exhaust emissions replace existing engines, the conclusions of the EPA Diesel HAD will need to be reevaluated.

More specifically, the EPA Diesel HAD states that the conclusions of the document apply to diesel exhaust in use today including both onroad and nonroad engines. The EPA Diesel HAD acknowledges that the studies were done on engines with older technologies generally for onroad and that “there have been changes in the physical and chemical composition of some DE [diesel exhaust] emissions (onroad vehicle emissions) over time, though there is no definitive information to show that the emission changes portend significant toxicological changes.” The EPA Diesel HAD further concludes that “taken together, these considerations have led to a judgment that the hazards identified from older-technology-based exposures are applicable to current-day exposures.” The diesel technology used for nonroad diesel engines typically lags that used for onroad engines which have been subject to PM standards since 1988.

Some of the epidemiologic studies discussed in the EPA Diesel HAD were conducted specifically on nonroad diesel engine emissions. In particular, one recent study examined bulldozer operators, graders, excavators, and full-time farm tractor drivers finding increased odds of lung cancer.[131] Another cohort study of operators of heavy construction equipment also showed increased lung cancer incidence for these workers.[132]

For the EPA Diesel HAD, EPA reviewed 22 epidemiologic studies in detail, finding increased lung cancer risk in 8 out of 10 cohort studies and 10 out of 12 case-control studies. Relative risk for lung cancer associated with exposure range from 1.2 to 2.6. In addition, two meta-analyses of occupational studies of diesel exhaust and lung cancer have estimated the smoking-adjusted relative risk of 1.35 and 1.47, examining 23 and 30 studies, respectively.[133,134] That is, these two studies show an overall increase in lung cancer for the exposed groups of 35 percent and 47 percent compared to the groups not exposed to diesel exhaust. In the EPA Diesel HAD, EPA selected 1.4 as a reasonable estimate of occupational relative risk for further analysis.

EPA generally derives cancer unit risk estimates to calculate population risk more precisely from exposure to carcinogens. In the simplest terms, the cancer unit risk is the increased risk associated with average lifetime exposure of 1 ug/m^3. EPA concluded in the Diesel HAD that it is not possible currently to calculate a cancer unit risk for diesel exhaust due to a variety of factors that limit the current studies, such as a lack of standard exposure metric for diesel exhaust and the absence of quantitative exposure characterization in retrospective studies.

However, in the absence of a cancer unit risk, the EPA Diesel HAD sought to provide additional insight into the possible ranges of risk that might be present in the population. Such insights, while not confident or definitive, nevertheless contribute to an understanding of the possible public health significance of the lung cancer hazard. The possible risk range analysis was developed by comparing a typical environmental exposure level to a selected range of occupational exposure levels and then proportionally scaling the occupationally observed risks according to the exposure ratio's to obtain an estimate of the possible environmental risk. If the occupational and environmental exposures are similar, the environmental risk would approach the risk seen in the occupational studies whereas a much higher occupational exposure indicates that the environmental risk is lower than the occupational risk. A comparison of environmental and occupational exposures showed that for certain occupations the exposures are similar to environmental exposures while, for others, they differ by a factor of about 200 or more.

The first step in this process is to note that the occupational relative risk of 1.4, or a 40 percent from increased risk compared to the typical 5 percent lung cancer risk in the U.S. population, translates to an increased risk of 2 percent (or 10^{-2}) for these diesel exhaust exposed workers. The Diesel HAD derived a typical nationwide average environmental exposure level of 0.8 ug./m^3 for diesel PM from on-highway sources for 1996. This estimate was based on national exposure modeling; the derivation of this exposure is discussed in detail in the EPA Diesel HAD. Diesel PM is a surrogate for diesel exhaust and, as mentioned above, has been classified as a carcinogen by some agencies.

The possible environmental risk range was estimated by taking the relative risks in the occupational setting, EPA selected 1.4 and converting this to absolute risk of 2% and then ratioing this risk by differences in the occupational vs environmental exposures of interest. A number of calculations are needed to accomplish this, and these can be seen in the EPA Diesel HAD. The outcome was that environmental risks from diesel exhaust using higher estimates of occupational exposure could range from a low of 10^{-4} to 10^{-5} or be as high as 10^{-3} if lower estimates of occupational exposure were used. Note that the environmental exposure of interest (0.8 ug/m^3) remains constant in this analysis, while the occupational exposure is a variable. The range of possible environmental risk is a reflection of the range of occupational exposures that could be associated with the relative and related absolute risk levels observed in the occupational studies.

While these risk estimates are exploratory and not intended to provide a definitive characterization of cancer risk, they are useful in gauging the possible range of risk based on reasonable judgement. It is important to note that the possible risks could also be higher or lower and a zero risk cannot be ruled out. Some individuals in the population may have a high tolerance to exposure from diesel exhaust and low cancer susceptibility. Also, one cannot rule out the possibility of a threshold of exposure below which there is no cancer risk, although evidence has not been seen or substantiated on this point.

Also, as discussed in the Diesel HAD, there is a relatively small difference between some occupational settings where increased lung cancer risk is reported and ambient environmental exposures. The potential for small exposure differences underscores the concerns about the appropriateness of extrapolation from occupational risk to ambient environmental exposure levels should be more confidently judged to be appropriate.

EPA also recently assessed air toxic emissions and their associated risk (the National-Scale Air Toxics Assessment or NATA for 1996), and we concluded that diesel exhaust ranks with other substances that the national-scale assessment suggests pose the greatest relative risk.[135] This national assessment estimates average population inhalation exposures to diesel PM in 1996 for nonroad as well as onroad sources. These are the sum of ambient levels in various locations weighted by the amount of time people spend in each of the locations. This analysis shows a somewhat higher diesel exposure level than the 0.8 $\mu g/m^3$ used to develop the risk perspective in the Diesel HAD. The average nationwide NATA mobile exposure levels are 1.44 $\mu g/m^3$ total with an onroad source contribution of 0.46 $\mu g/m^3$ and a nonroad source contribution of 0.98 $\mu g/m^3$. The average urban exposure was 1.64 $\mu g/m^3$ and the average rural exposure was 0.55 $\mu g/m^3$. In five percent of urban census tracts across the United States, average exposures were above 4.33 $\mu g/m^3$. The EPA Diesel HAD states that use of the NATA exposure estimates instead of the 0.8 $\mu g/m^3$ estimate results in a similar risk perspective.

In summary, even though EPA does not have a specific carcinogenic potency with which to accurately estimate the carcinogenic impact of diesel exhaust, the likely hazard to humans together with the potential for significant environmental risks leads us to conclude that diesel exhaust emissions need to be reduced from nonroad engines in order to protect public health. The following factors lead to our determination.

1 EPA has officially designated diesel exhaust has been designed a likely human carcinogen due to inhalation at environmental exposure. Other organizations have made similar determinations.
2. The entire population is exposed to various levels of diesel exhaust. The higher exposures at environmental levels is comparable to some occupational exposure levels, so that environmental risk could be the same as, or approach, the risk magnitudes observed in the occupational epidemiologic studies.
3. The possible range of risk for the general US population due to exposure to diesel exhaust is 10^{-3} to 10^{-5} although the risk could be lower and a zero risk cannot be ruled out.

Thus, the concern for a carcinogenicity hazard resulting from diesel exhaust exposures is longstanding based on studies done over many years. This hazard may be widespread due to the ubiquitous nature of exposure to diesel exhaust.

2.2.1.2 Other Health Effects of Diesel Exhaust

The acute and chronic exposure-related effects of diesel exhaust emissions are also of concern to the Agency. The Diesel HAD established an inhalation Reference Concentration (RfC) specifically based on animal studies of diesel exhaust. An RfC is defined by EPA as “an estimate of a continuous inhalation exposure to the human population, including sensitive subgroups, with uncertainty spanning perhaps an order of magnitude, that is likely to be without appreciable risks of deleterious noncancer effects during a lifetime." EPA derived the RfC from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects.[136],[137],[138],[139] The diesel RfC is based on a "no observable adverse effect" level of 144 ug/m^3 that is further reduced by applying uncertainty factors of 3 for interspecies extrapolation and 10 for human variations in sensitivity. The resulting RfC derived in the Diesel HAD is 5 ug/m^3 for diesel exhaust as measured by diesel PM. This RfC does not consider allergenic effects such as those associated with asthma or immunologic effects. There is growing evidence that diesel exhaust can exacerbate these effects, but the exposure-response data is presently lacking to derive an RfC.

While there have been relatively few human studies associated specifically with the noncancer impact of diesel PM alone, diesel PM is frequently part of the ambient particles studied in numerous epidemiologic studies. Conclusions that health effects associated with ambient PM in general is relevant to diesel PM is supported by studies that specifically associate observable human noncancer health effects with exposure to diesel PM. As described in the Diesel HAD, these studies include some of the same health effects reported for ambient PM, such as respiratory symptoms (cough, labored breathing, chest tightness, wheezing), and chronic respiratory disease (cough, phlegm, chronic bronchitis and suggestive evidence for decreases in pulmonary function). Symptoms of immunological effects such as wheezing and increased allergenicity are also seen. Studies in rodents, especially rats, show the potential for human inflammatory effects in the lung and consequential lung tissue damage from chronic diesel exhaust inhalation exposure. The Diesel HAD notes that acute or short-term exposure to diesel exhaust can cause acute irritation (e.g., eye, throat, bronchial), neurophysiological symptoms (e.g., lightheadedness, nausea), and respiratory symptoms (cough, phlegm). There is also evidence for an immunologic effect such as the exacerbation of allergenic responses to known allergens and asthma-like symptoms.[140,141,142,143] The Diesel HAD lists numerous other studies as well. Also, as discussed in more detail previously, in addition to its contribution to ambient PM inventories, diesel PM is of special concern because it has been associated with an increased risk of lung cancer.

The Diesel HAD also briefly summarizes health effects associated with ambient PM and the EPA's annual NAAQS of 15 ug/m^3. There is a much more extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The RfC is not meant to say that 5 ug/m^3 provides adequate public health protection for ambient $PM_{2.5}$. In fact, there may be benefits to reducing diesel PM below 5 ug/m^3 since diesel PM is a major contributor to ambient $PM_{2.5}$.[G]

Also, as mentioned earlier in the health effects discussion for $PM_{2.5}$, there are a number of other health effects associated with PM in general, and motor vehicle exhaust including diesels in

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[G] It should again be noted that recent epidemiologic studies (such as by Schwartz, Laden, and Zanobetti) of ambient $PM_{2.5}$ do not indicate a threshold of effects at low concentrations.

particular, that provide additional evidence for the need for significant emission reductions from nonroad diesel sources.

As indicated earlier, a number of recent studies have associated living near roadways with adverse health effects. Two of the studies cited earlier will be mentioned again here as examples of the type of work that has been done. A Dutch study (discussed earlier by G. Hoek and others) of a population of people 55-69 years old found that there was an elevated risk of heart and lung related mortality among populations living near high traffic roads. In a review discussed earlier of studies (by R. Delfino) of the respiratory health of people living near roadways, another publication indicated that the risk of asthma and related respiratory disease appeared elevated in people living near heavy traffic. These studies offer evidence that people exposed most directly to emissions from mobile sources including those from diesels face an elevated risk of illness or death.

All of these health effects plus the designation of diesel exhaust as a likely human carcinogen provide ample health justification for control.

2.2.1.3 Diesel Exhaust PM Ambient Levels

Because diesel PM is part of overall ambient PM and cannot be easily distinguished from overall PM, we do not have direct measurements of diesel PM in the ambient air. Diesel PM concentrations are estimated instead using one of three approaches: 1) ambient air quality modeling based on diesel PM emission inventories; 2) using elemental carbon concentrations in monitored data as surrogates; or 3) using the chemical mass balance (CMB) model in conjunction with ambient PM measurements. (Also, in addition to CMB, UNMIX/PMF have also been used). Estimates using these three approaches are described below. In addition, estimates developed using the first two approaches above are subjected to a statistical comparison to evaluate overall reasonableness of estimated concentrations from ambient air quality modeling. It is important to note that, while there are inconsistencies in some of these studies on the relative importance of gasoline and diesel PM, the studies which are discussed in the Diesel HAD all show that diesel PM is a significant contributor to overall ambient PM. Some of the studies differentiate nonroad from on-highway diesel PM.

2.2.1.3.1 Toxics Modeling and Methods

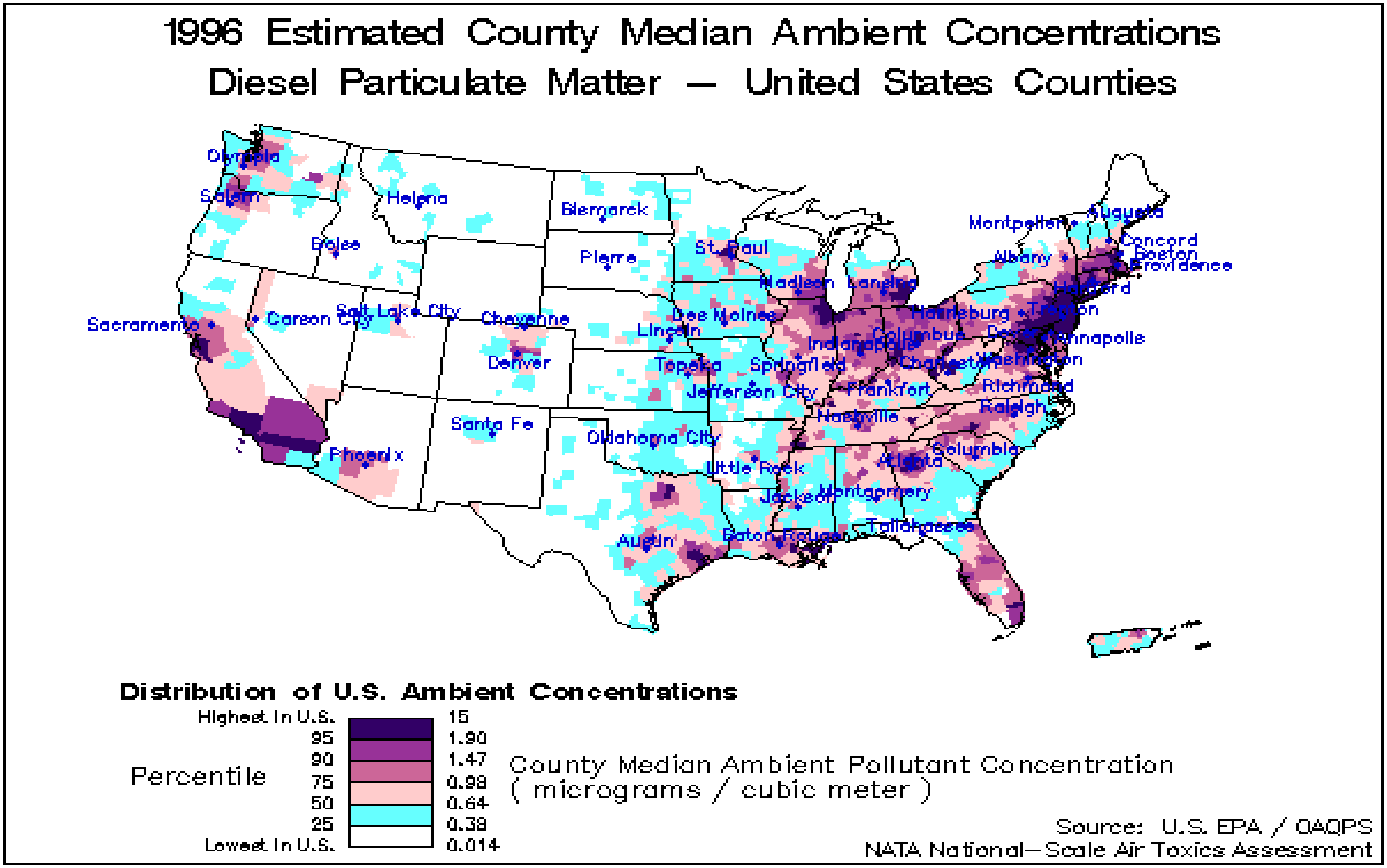
In addition to the general ambient PM modeling conducted for this proposal, diesel PM concentrations for 1996 were recently estimated as part of the National-Scale Air Toxics Assessment (NATA; EPA, 2002). In this assessment, the PM inventory developed for the recent regulation promulgating 2007 heavy duty vehicle standards was used (EPA, 2000). Note that the nonroad inventory used in this modeling was based on an older version of the draft NONROAD Model which showed higher diesel PM than the current version, so the ambient concentrations may be biased high. Ambient impacts of mobile source emissions were predicted using the Assessment System for Population Exposure Nationwide (ASPEN) dispersion model.

From the NATA 1996 modeling, overall mean annual national ambient diesel PM levels of 2.06 µg/m^3 were calculated with a mean of 2.41 in urban counties and 0.74 in rural counties. Table 2.2.1-1 below summarizes the distribution of average ambient concentrations to diesel PM at the national scale. Over half of the diesel PM can be attributed to nonroad diesels. A map of county median concentrations is provided in Figure 2.2.1-1. While the high median concentrations are clustered in the Northeast, Great Lake States and California, areas of high median concentrations are distributed throughout the U.S.

Table 2.2.1-1
Distribution of Average Ambient Concentrations of
Diesel PM at the National Scale in the 1996 NATA Assessment.

	Nationwide (µg/m^3)	Urban (µg/m^3)	Rural (µg/m^3)
5th Percentile	0.33	0.51	0.15
25th Percentile	0.85	1.17	0.42
Average	2.06	2.41	0.74
75th Percentile	2.45	2.7	0.97
95th Percentile	5.37	6.06	1.56
Onroad Contribution to Average	0.63	0.72	0.27
Nonroad Contribution to Average	1.43	1.69	0.47

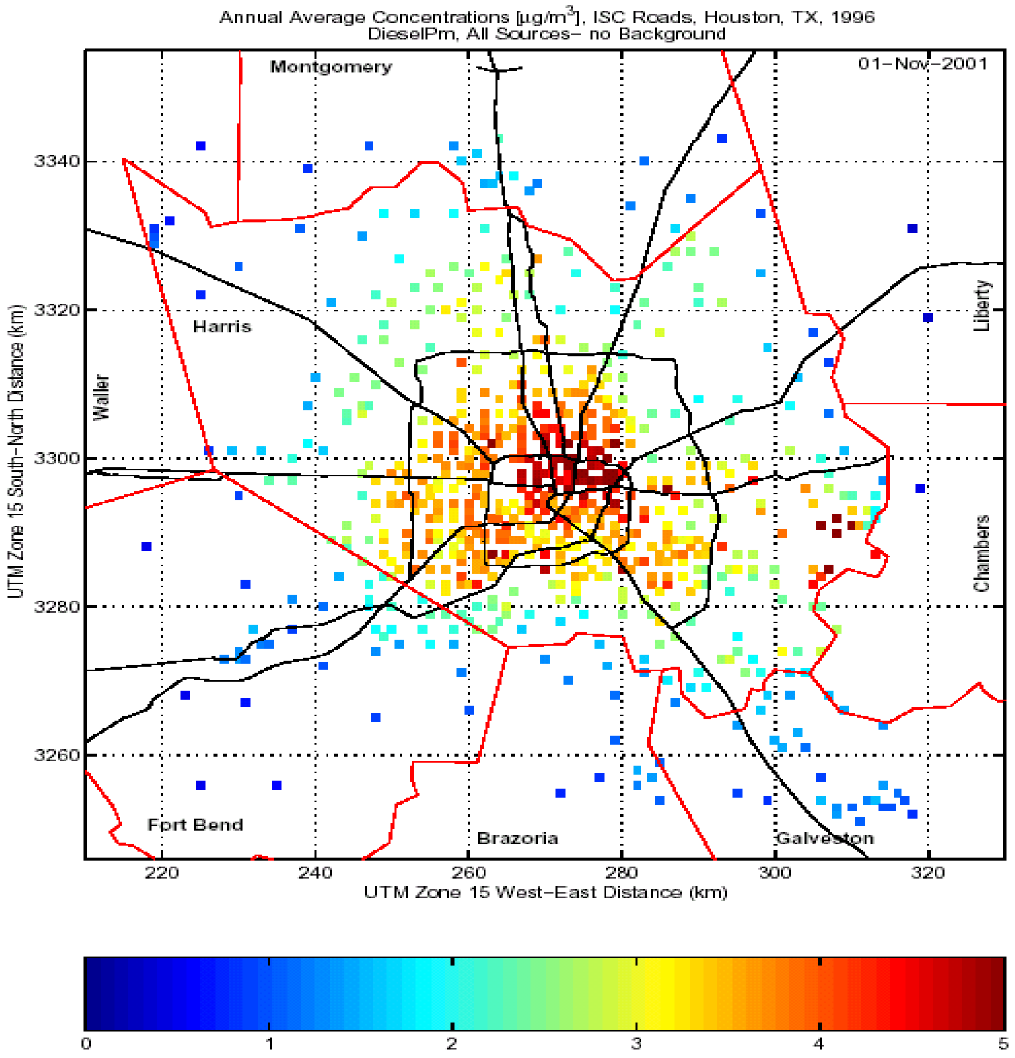
Figure 2.2.1-1
Estimated County Median Concentrations of Diesel Particulate Matter



Source: EPA National-Scale Air Toxics Assessment for 1996.

Diesel PM concentrations were also recently modeled across a representative urban area, Houston, Texas, for 1996, using the Industrial Source Complex Short Term (ISCST3) model.[144] The methodology used to model diesel PM concentrations is the same as the methodology used for benzene and other hazardous air pollutants, as described in a recent EPA technical report.[145] For Harris County, which has the highest traffic density in Houston area, link-based diesel PM emissions were estimated for highway mobile sources, using diesel PM emission rates developed for the recent EPA 2007 heavy duty engine and highway diesel fuel sulfur control rule.[146] This link-based modeling approach is designed to specifically account for local traffic patterns within the urban center, including diesel truck traffic along specific roadways. For other counties in the Houston metropolitan area, county level emission estimates from highway vehicles were allocated to one kilometer grid cells based on total roadway miles. Nonroad diesel emissions for Houston area counties were obtained from the inventory done for the 2007 heavy duty rule, and allocated to one kilometer grid cells using activity surrogates. The modeling in Houston suggests strong spatial gradients (on the order of a factor of 2-3 across a modeling domain) for diesel PM and indicates that “hotspot” concentrations can be very high. Values as high as 8 $\mu g/m^3$ at were estimated at a receptor versus a 3 $\mu g/m^3$ average in Houston. Such “hot spot” concentrations suggest both a high localized exposure plus higher estimated average annual exposure levels for urban centers than what has been estimated in assessments such as NATA 1996, which are designed to focus on regional and national scale averages. Figure 2.2.1-2 depicts the spatial distribution of diesel PM concentrations in Houston.

Figure 2.2.1-2 Annual Average Ambient Concentrations
of Diesel PM in Houston, 1996, based on Dispersion Modeling
Using Industrial Source Complex Short Term (ISCST3) model.



2.2.1.3.2 Elemental Carbon Measurements

As shown in Figures 2.1.1-1 to 3, the carbonaceous component is significant in ambient PM. The carbonaceous component consists of organic carbon and elemental carbon. Monitoring data on elemental carbon concentrations can be used as a surrogate to determine ambient diesel PM concentrations. Elemental carbon is a major component of diesel exhaust, contributing to approximately 60-80 percent of diesel particulate mass, depending on engine technology, fuel type, duty cycle, lube oil consumption, and state of engine maintenance. In most areas, diesel engine emissions are major contributors to elemental carbon, with other potential sources including gasoline exhaust, combustion of coal, oil, or wood, charbroiling, cigarette smoke, and road dust. Because of the large portion of elemental carbon in diesel particulate matter, and the fact that diesel exhaust is one of the major contributors to elemental carbon in most areas, ambient diesel PM concentrations can be bounded using elemental carbon measurements.

The measured mass of elemental carbon at a given site varies depending on the measurement technique used. Moreover, to estimate diesel PM concentration based on elemental carbon level, one must first estimate the percentage of PM attributable to diesel engines and the percentage of elemental carbon in diesel PM. Thus, there are significant uncertainties in estimating diesel PM concentrations using an elemental carbon surrogate. Also, there are issues with the measurement methods used for elemental carbon. Many studies used thermal optimal transmission (TOT), the NIOSH method developed at Sunset laboratories. Other studies used thermal optical reflectance (TOR), a method developed by Desert Research Institute. EPA has developed multiplicative conversion factors to estimate diesel PM concentrations based on elemental carbon levels.[147] Results from several source apportionment studies were used to develop these factors.[148, 149, 150, 151, 152, 153, 154] Average conversion factors were compiled together with lower and upper bound values. Conversion factors (CFs) were calculated by dividing the diesel $PM_{2.5}$ concentration reported in these studies by the total organic carbon or elemental carbon concentrations also reported in the studies. Table 2.2.1-2 presents the minimum, maximum, and average EC conversion factors as a function of:

- Measurement technique
- East or West US
- Season
- Urban or rural

The reported minimum, maximum, and average values in Table 2.2.1-2 are the minima, maxima, and arithmetic means of the EC conversion factors across all sites (and seasons, where applicable) in the given site subset. For the TOT data collected in the East, the minimum, maximum, and average conversion factors are all equal. This is because these values were based only on one study where the data were averaged over sites, by season.[155] Depending on the measurement technique used, and assumptions made in converting elemental carbon concentration to diesel PM concentration, average nationwide concentrations for current years of diesel PM estimated from elemental carbon data range from about 1.2 to 2.2 $\mu g/m^3$. EPA has compared these estimates based on elemental carbon measurements to modeled concentrations in the NATA for 1996. Results of comparisons of mean percentage differences are presented in Table 2.2.1-3. These results show that the two sets of data agree reasonably well, with estimates for the majority of sites within a factor of 2, regardless of the measurement technique or methodology for converting elemental carbon to diesel PM concentration. Agreement was better when modeled concentrations were adjusted to reflect recent changes in the nonroad inventory. The best model performance based on the fraction of modeled values within 100 % of the monitored value is for the DPM-maximum value which reflects changes to the nonroad inventory model. The corresponding fractions of modeled values within 100 % of the monitored value are

73 % for TOR sites, 80 % for TOT sites, and 92 % for TORX sites.   All in all, this performance compares favorably with the model to monitor results for other pollutants assessed in NATA, with the exception of benzene, for which the performance of the NATA modeling was better.

2.2.1.3.3 Chemical Mass Balance Receptor Modeling and Source Apportionment

The third approach for estimating ambient diesel PM concentrations uses the chemical mass balance (CMB) model for source apportionment in conjunction with ambient PM measurements and chemical source "fingerprints" to estimate ambient diesel PM concentrations. The CMB model uses a statistical fitting technique to determine how much mass from each source would be required to reproduce the chemical fingerprint of each speciated ambient monitor. Inputs to the CMB model applied to ambient $PM_{2.5}$ include measurements made at an air monitoring site and measurements made of each of the source types suspected to affect the site. The CMB model uses a statistical fitting technique ("effective variance weighted least squares") to determine how much mass from each source would be required to reproduce the chemical fingerprint of each speciated ambient monitor. This calculation is based on optimizing the sum of sources, so that the difference between the ambient monitor and the sum of sources is minimized. The optimization technique employs "fitting species" that are related to the sources. The model assumes that source profiles are constant over time, that the sources do not interact or react in the atmosphere, that uncertainties in the source fingerprints are well-represented, and that all sources are represented in the model.

This source apportionment technique presently does not distinguish between onroad and nonroad but, instead, gives diesel PM as a whole. One can allocate the diesel PM numbers based on the inventory split between onroad and nonroad diesel although this allocation was not done in the studies published to date. This source apportionment technique can though distinguish between diesel and gasoline PM. Caution in interpreting CMB results is warranted, as the use of fitting species that are not specific to the sources modeled can lead to misestimation of source contributions. Ambient concentrations using this approach are generally about 1 $\mu g/m^3$ annual average.   UNMIX/PMF models show similar results.

Table 2.2.1-2
Summary of Calculated Elemental Carbon (EC) Conversion Factors
(Conversion factors to convert total EC to diesel PM$_{2.5}$ concentration)

Ambient Measurement Technique: TOT or TOR	East or West	Season	Location Type General	MIN[a]	MAX[a]	AVERAGE[a]	Recommended Conversion Factors	
							EAST	WEST
TOT	East	Fall (Q4)	Mixed	2.3	2.3	2.3	X	
	East	Spring (Q2)	Mixed	2.4	2.4	2.4	X	
	East	Summer (Q3)	Mixed	2.1	2.1	2.1	X	
	East	Winter (Q1)	Mixed	2.2	2.2	2.2	X	
	West	Unknown	Urban	1.2	2.4	1.6		X
TOT Total				1.2	2.4	2.0		
TOR		Winter	Rural	0.6	1.0	0.8	X	X
		Winter	Urban	0.5	1.0	0.7	X	X
	Winter Total			0.5	1.0	0.8		
TOR Total				0.5	1.0	0.8		
Grand Total				0.5	2.4	1.3		

Source: ICF Consulting for EPA, 2002, Office of Transportation and Air Quality. Report No. EPA420-D-02-004.
[a] Minimum, maximum, or average value across all sites of the estimated conversion factors.

TOT = thermal optimal transmission, the NIOSH method developed at Sunset laboratories.
TOR = thermal optical reflectance, a method developed by Desert Research Institute.

Table 2.2.1-3
Summary of Differences Between the Nearest Modeled Concentration
of Diesel Pm from the National Scale Air Toxics Assessment and Monitored Values
Based on Elemental Carbon Measurements (Diesel PM model-to-measurement comparison)

Modeled Variable[a]	Monitored Variable[b]	N	Mean Modeled Value	Mean Monitored Value	Mean Difference	Mean % Difference	Fraction of Modeled Values Within			
							10%	25%	50%	100%
concnear	TOR	15	1.56	0.94	0.63	100	0.07	0.13	0.53	0.53
concnear2	TOR	15	1.20	0.94	0.26	56	0.07	0.13	0.47	0.60
concnear	TORH	15	1.56	1.16	0.40	62	0.00	0.07	0.40	0.60
concnear2	TORH	15	1.20	1.16	0.04	26	0.00	0.07	0.33	0.73
concnear	TORL	15	1.56	0.64	0.92	190	0.13	0.40	0.47	0.53
concnear2	TORL	15	1.20	0.64	0.55	126	0.07	0.33	0.47	0.53
concnear	TOT	95	2.61	1.73	0.88	80	0.12	0.21	0.45	0.68
concnear2	TOT	95	2.05	1.73	0.32	42	0.11	0.37	0.53	0.77
concnear	TOTH	95	2.61	2.10	0.52	61	0.11	0.22	0.46	0.74
concnear2	TOTH	95	2.05	2.10	-0.05	27	0.11	0.35	0.53	0.80
concnear	TOTL	95	2.61	1.52	1.09	101	0.09	0.17	0.43	0.63
concnear2	TOTL	95	2.05	1.52	0.52	58	0.09	0.32	0.52	0.72
concnear	TORX	88	2.31	1.70	0.61	47	0.10	0.30	0.59	0.78
concnear2	TORX	88	1.81	1.70	0.11	15	0.17	0.30	0.59	0.85
concnear	TORXH	88	2.31	2.23	0.08	13	0.11	0.26	0.60	0.84
concnear2	TORXH	88	1.81	2.23	-0.42	-12	0.08	0.22	0.52	0.92
concnear	TORXL	88	2.31	1.19	1.12	110	0.10	0.26	0.41	0.65
concnear2	TORXL	88	1.81	1.19	0.62	65	0.14	0.31	0.52	0.74

Source: ICF Consulting for EPA, 2002, Office of Transportation and Air Quality. Report No. EPA420-D-02-004.

[a] Modeled variable:

concnear	Nearest modeled DPM concentration from the 1996 NATA
concnear2	Nearest modeled DPM concentration with NATA concentrations adjusted to be consistent with changes to the nonroad inventory model

[b] Monitored variable:

TOR	EC value multiplied by TOR average correction factor
TORH	EC value multiplied by TOR maximum correction factor
TORL	EC value multiplied by TOR minimum correction factor
TOT	EC value multiplied by TOT average correction factor
TOTH	EC value multiplied by TOT maximum correction factor
TOTL	EC value multiplied by TOR minimum correction factor
TORX	TOR values plus the TOR equivalent values multiplied by TOR average correction factor
TORXH	TOR values plus the TOR equivalent values multiplied by TOR maximum correction factor
TORXL	TOR values plus the TOR equivalent values multiplied by TOR minimum correction factor

Because of the correlation of diesel and gasoline exhaust PM emissions in time and space, chemical molecular species that provide markers for separation of these sources have been sought. Recent advances in chemical analytical techniques have facilitated the development of sophisticated molecular source profiles, including detailed speciation of organic compounds, which allow the apportionment of particulate matter to gasoline and diesel sources with increased certainty. As mentioned previously, however, caution in interpreting CMB results is warranted. Markers that have been used in CMB receptor modeling have included elemental carbon, polycyclic aromatic hydrocarbons (PAHs), organic acids, hopanes, and steranes.

It should be noted that since receptor modeling is based on the application of source profiles to ambient measurements, this estimate of diesel PM concentrations includes the contribution from on-highway and nonroad sources of diesel PM, although no study to date has included source profiles from nonroad engines. Engine operations, fuel properties, regulations, and other factors may distinguish nonroad diesel engines from their on-highway counterparts.

In addition, this model accounts for primary emissions of diesel PM only; the contribution of secondary aerosols is not included. The role of secondarily formed organic PM in urban $PM_{2.5}$ concentrations is not known, particularly from diesel engines.

The first major application of organic tracer species in applying the CMB model evaluated ambient $PM_{2.0}$ in Los Angeles, CA sampled in 1982.[156] This study was the first to distinguish gasoline and diesel exhaust. CMB model application at four sites in the Los Angeles area estimated ambient diesel $PM_{2.0}$ concentrations to be 1.02-2.72 $\mu g/m^3$. It should be noted that diesel PM estimates are derived from source profiles measured on in-use diesel trucks.

Another major study examining diesel exhaust separately from gasoline exhaust and other sources is the Northern Front Range Air Quality Study (NFRAQS).[157] This study was conducted in the metropolitan Denver, CO area during 1996-1997. The NFRAQS study employed a different set of chemical species, including PAHs and other organics to produce source profiles for a diverse range of mobile sources, including “normal emitting” gasoline vehicles, cold start gasoline vehicles, high emitting gasoline vehicles, and diesel vehicles. Average source contributions from diesel engines in NFRAQS were estimated to be 1.7 $\mu g/m^3$ in an urban area, and 1.2 $\mu g/m^3$ in a rural area. Source profiles in this study were based on onroad vehicles.

The CMB model was applied in California’s San Joaquin Valley during winter 1995-1996.[158] The study employed similar source tracers as the earlier study of Los Angeles PM2.0, in addition to other more specific markers. Diesel PM source contribution estimates in Bakersfield, CA were 3.92 and 5.32 during different measurement periods. Corresponding estimates in Fresno, CA were 9.68 and 5.15 $\mu g/m^3$. In the Kern Wildlife Refuge, diesel PM source contribution estimates were 1.32 and 1.75 $\mu g/m^3$ during the two periods.

The CMB model was applied in the southeastern U.S. on data collected during the Southeastern Aerosol Research and Characterization (SEARCH) study (Zheng et al., 2002). Modeling was conducted on data collected during April, July, and October 1999 and January 2000. Examining ambient monitors in urban, suburban, and rural areas, the modeled annual average contribution of primary diesel emissions to ambient $PM_{2.5}$ was 3.20-7.30 $\mu g/m^3$ in N. Birmingham, AL, 1.02-2.43 $\mu g/m^3$ in Gulfport, MS, 3.29-5.56 $\mu g/m^3$ in Atlanta, GA, and Pensacola, FL 1.91-3.07 $\mu g/m^3$ which represented the urban sites in the study. Suburban sites in the study were located outside Pensacola, FL (1.08-1.73 $\mu g/m^3$). Rural sites were located in Centreville, AL (0.79-1.67 $\mu g/m^3$), Oak Grove, MS (1.05-1.59 $\mu g/m^3$), and Yorkville, GA (1.07-2.02 $\mu g/m^3$).

The CMB model was applied to ambient $PM_{2.5}$ data collected during a severe photochemical smog event during 1993 in Los Angeles using organic tracers.[159] Modeled concentrations of diesel contributions to $PM_{2.5}$ during this episode were conducted for Long Beach (8.33 µg/m^3), downtown Los Angeles (17.9 µg/m^3), Azusa (14.9 µg/m^3), and Claremont, CA (7.63 µg/m^3).

While these studies provide an indication that diesel exhaust is a substantial contributor to ambient $PM_{2.5}$ mass, they should still be viewed with caution. CMB modeling depends on ensuring the use of highly specific tracer species. If sources, such as nonroad diesel engines, are chemically different from other sources, including onroad diesel trucks, the CMB model can misestimate source contributions. Nevertheless, these studies provide information that is complementary to source-oriented air quality modeling (discussed above). From these studies, it is apparent that diesel exhaust is a substantial contributor to ambient $PM_{2.5}$, even in remote and rural areas.

2.2.1.4 Diesel Exhaust PM Exposures

Exposure of people to diesel exhaust depends on their various activities, the time spent in those activities, the locations where these activities occur, and the levels of diesel exhaust pollutants (such as PM) in those locations. While ambient levels are specific for a particular location, exposure levels account for such factors as a person moving from location to location, proximity to the emission source, and whether the exposure occurs in an enclosed environment.

2.2.1.4.1 Occupational Exposures

Diesel particulate exposures have been measured for a number of occupational groups over various years but generally for more recent years (1980s and later) rather than earlier years. Occupational exposures had a wide range varying from 2 to 1,280 µg/m^3 for a variety of occupational groups including miners, railroad workers, firefighters, air port crew, public transit workers, truck mechanics, utility linemen, utility winch truck operators, fork lift operators, construction workers, truck dock workers, short-haul truck drivers, and long-haul truck drivers. These individual studies are discussed in the Diesel HAD.

The highest exposure to diesel PM is for workers in coal mines and noncoal mines which are as high a 1,280 µg/m^3 as discussed in the Diesel HAD. The National Institute of Occupational Safety and Health (NIOSH) has estimated a total of 1,400,000 workers are occupationally exposed to diesel exhaust from on-road and nonroad equipment.

Many measured or estimated occupational exposures are for on-road diesel engines and some are for school buses.[160, 161, 162, 163] Also, some (especially the higher ones) are for occupational groups (fork lift operator, construction workers, or mine workers) who would be exposed to nonroad diesel exhaust. Sometimes, as is the case for the nonroad engines, there are only estimates of exposure based on the length of employment or similar factors rather than a µg/m^3 level. Estimates for exposures to diesel PM for diesel fork lift operators have been made that range from 7 to 403 µg/m^3 as reported in the Diesel HAD. In addition, the Northeast States for Coordinated Air Use Management (NESCAUM) is presently measuring occupational exposures to particulate and elemental carbon near the operation of various diesel non-road equipment. Exposure groups include agricultural farm operators, grounds maintenance personnel (lawn and garden equipment), heavy equipment operators conducting multiple job tasks at a construction site, and a saw mill crew at a lumber yard. Samples will be obtained in the breathing zone of workers. These data, tentatively scheduled to be available in about a year, will be useful in quantifying high localized exposure levels in the vicinity of nonroad equipment.[164] Some initial results are expected in late 2003.

2.2.1.4.2 Ambient Exposures in the General Population

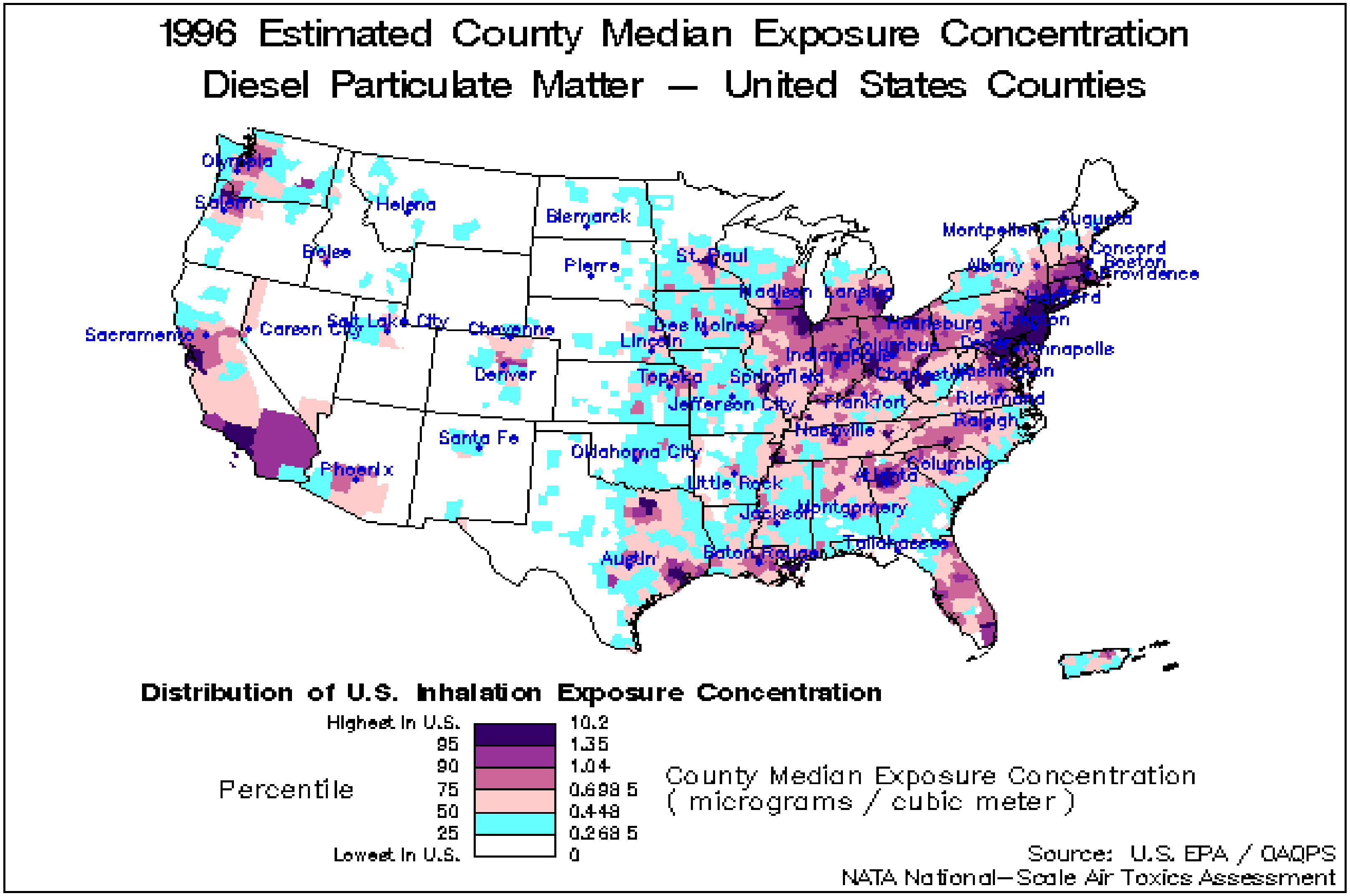
Currently, personal exposure monitors for PM cannot differentiate diesel from other PM. Thus, we use modeling to estimate exposures. Specifically, exposures for the general population are estimated by first conducting dispersion modeling of both on-highway and nonroad diesel emissions, described above, and then by conducting exposure modeling. The most comprehensive modeling for cumulative on-road and non-road exposures to diesel PM is the NATA. This assessment calculates exposures of the national population as a whole to a variety of air toxics, including diesel PM. As discussed previously, the ambient levels are calculated using the ASPEN dispersion model. As discussed above, the preponderance of modeled diesel PM concentrations are within a factor of 2 of diesel PM concentrations estimated from elemental carbon measurements.[165] This comparison adds credence to the modeled ASPEN results and associated exposure assessment.

The modeled concentrations for calendar year 1996 are used as inputs into an exposure model called the Hazardous Air Pollution Exposure Model (HAPEM4) to calculate exposure levels. Average exposures calculated nationwide are 1.44 $\mu g/m^3$ with levels of 1.64 $\mu g/m^3$ for urban counties and 0.55 $\mu g/m^3$ for rural counties. Again, nonroad diesel emissions account for over half of the this exposure. Table 2.2.1-4 summarizes the distribution of average exposure concentrations to diesel PM at the national scale in the 1996 NATA assessment. Figure 2.2.1-3 presents a map of the distribution of median exposure concentrations for U.S. counties.

Table 2.2.1-4
Distribution of Average Exposure Concentrations to
Diesel PM at the National Scale in the 1996 NATA Assessment.

	Nationwide ($\mu g/m^3$)	Urban ($\mu g/m^3$)	Rural ($\mu g/m^3$)
5th Percentile	0.16	0.29	0.07
25th Percentile	0.58	0.81	0.29
Average	1.44	1.64	0.55
75th Percentile	1.73	1.91	0.67
95th Percentile	3.68	4.33	1.08
Onroad Contribution to Average	0.46	0.52	0.21
Nonroad Contribution to Average	0.98	1.12	0.34

Figure 2.2.1-3
Estimated County Median Exposure Concentrations of Diesel Particulate Matter



Source: EPA National-Scale Air Toxics Assessment for 1996.

As explained earlier, the fact that these levels are below the 5 ug/m^3 RfC (which is based on limited animal studies on diesel PM) does not necessarily mean that there are no adverse health implications from overall PM$_{2.5}$ exposure. The health studies for the PM$_{2.5}$ NAAQS are far more encompassing than the limited animal studies used to develop the RfC for diesel exhaust, and, also, the NAAQS applies to PM$_{2.5}$ regardless of its composition. In other words, all of the health effects cited in the implementation of the PM$_{2.5}$ NAAQS apply to diesel PM.

2.2.1.4.3 Ambient Exposures to Diesel Exhaust PM in Microenvironments

One common microenvironment for ambient exposures to diesel exhaust PM is beside freeways. Although freeway locations are associated mostly with onroad rather than nonroad diesels, there are many similarities between on-highway and nonroad diesel emissions as discussed in the Diesel HAD. Also, similar spatial gradients in concentrations would be expected where nonroad equipment is used. The California Air Resources Board (CARB) has measured elemental carbon near the Long Beach Freeway in 1993.[166] Levels measured ranged from 0.4 to 4.0 µg/m^3 (with one value as high as 7.5 ug/m^3) above background levels. Microenvironments associated with nonroad engines would include construction zones. PM and elemental carbon samples are being collected by NESCAUM in the immediate area of the nonroad engine operations (such as at the edge or fence line of the construction zone). Besides PM and elemental carbon levels, various toxics such as benzene, 1,3-butadiene, formaldehyde, and acetaldehyde will be sampled. The results should be especially useful since they focus on microenvironments affected by nonroad diesels.

Also, EPA is funding research in Fresno, California to measure indoor and outdoor PM component concentrations in the homes of over 100 asthmatic children. Some of these homes are located near agricultural, construction, and utility nonroad equipment operations. This work will measure infiltration of elemental carbon and other PM components to indoor environments. The project also evaluates lung function changes in the asthmatic children during fluctuations in exposure concentrations and compositions. This information may allow an evaluation of adverse health effects associated with exposures to elemental carbon and other PM components from on-road and nonroad sources.

2.2.2 Gaseous Air Toxics

Nonroad diesel engine emissions contain several substances known or suspected as human or animal carcinogens, or have noncancer health effects. These other compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, dioxin, and polycyclic organic matter (POM). For some of these pollutants, nonroad diesel engine emissions are believed to account for a significant proportion of total nationwide emissions. All of these compounds were identified as national or regional “risk” drivers in the 1996 NATA. That is, these compounds pose a significant portion of the total inhalation cancer risk to a significant portion of the population. Mobile sources contribute significantly to total emissions of these air toxics. As discussed later in this section, this proposed rulemaking will result in significant reductions of these emissions.

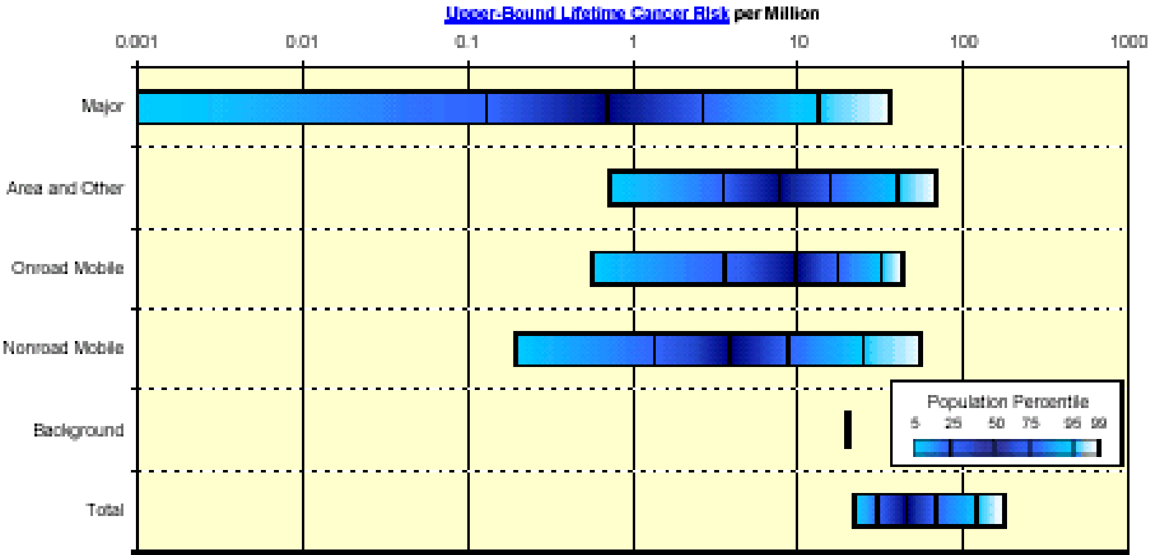
Nonroad engines are major contributors to nationwide cancer risk from air toxic pollutants, as indicated by the NATA 1996.[167] In fact, this study and the National Toxics Inventory (NTI) for 1996 are used throughout this section for toxics inventory information for nonroad sources.[168] Also, a supplemental paper provides more detail on nonroad diesel.[169] In addition, a paper published by the Society of Automotive Engineers gives future projections to 2007 for these air toxics.[170] These references form the basis for much of what will be discussed in this section.

Figure 2.2.2-1 summarizes the contribution of nonroad engines to average nationwide lifetime upper bound cancer risk from outdoor sources in the 1996 NATA. These data do not include the cancer risk from diesel PM since EPA does not presently have a potency for diesel particulate/exhaust. Figure 2.2.2-2 depicts the nonroad engine contribution to average nationwide inhalation exposure for benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. These compounds are all known or suspected human carcinogens, except for acrolein, which has serious noncancer health effects. All of these compounds were identified as national or regional risk drivers in the 1996 NATA, and mobile sources contribute significantly to total emissions in NATA. As indicated previously, NATA exposure and risk estimates are based on air dispersion modeling using the ASPEN model. Comparisons of the predicted concentrations from the model to monitor data indicate good agreement for benzene, where the ratio of median modeled concentrations to monitor values is 0.92, and results are within a factor of two at almost 90 percent of monitors.[171] Comparisons with aldehydes indicate significantly lower modeled concentrations than monitor values. Comparisons with 1,3-butadiene have not been done. Previously, extensive work was done on gaseous air toxic emissions including those from nonroad diesel and reported in EPA’s 1993 Motor Vehicle-Related Air Toxics Study.[172] The EPA proposed rulemaking will result in reductions of these emissions. Dioxin and some POM compounds have also been identified as probable human carcinogens and are emitted by mobile sources, although nonroad sources are less than 1% of total emissions for these compounds.

Figure 2.2.2-1

1996 Risk Characterization

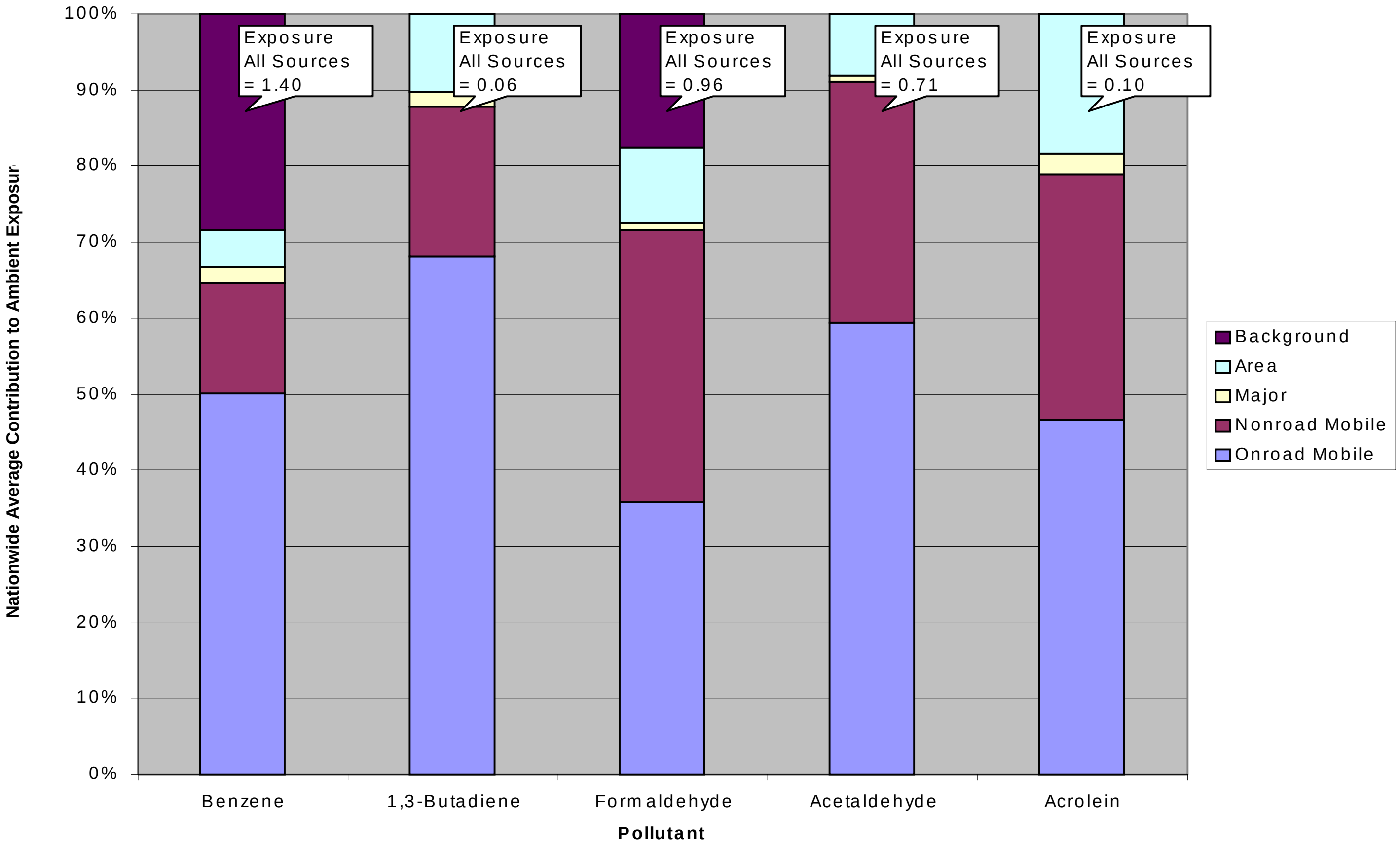
Distribution of lifetime cancer risk for the US population, based on 1996* exposure to 29 carcinogenic air pollutants from various source sectors



** Results are based on inhalation exposure to outdoor sources only. Although these results assume continuous exposure to 1996 levels of air toxics over a lifetime, current and planned control programs are expected to substantially reduce these exposures and associated cancer risk for some pollutants. See additional information on the following page.*

Figure 2.2.2-2

Contribution of Source Sectors to Average Annual Nationwide Inhalation Exposure to Air Toxics in 1996



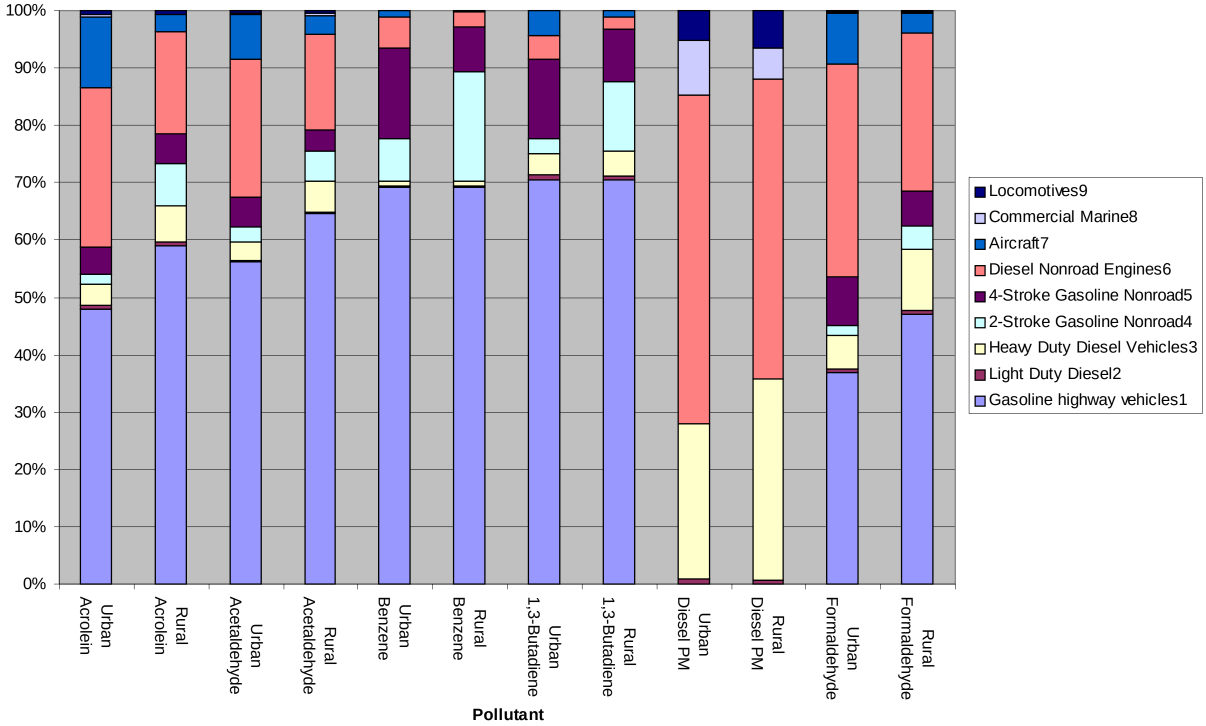
Source: National Scale Air Toxics Assessment.

2.2.2.1 Benzene

Benzene is an aromatic hydrocarbon which is present as a gas in both exhaust and evaporative emissions from mobile sources. Benzene accounts for one to two percent of the exhaust hydrocarbons, expressed as a percentage of total organic gases (TOG), in diesel engines.[173, 174] For gasoline-powered highway vehicles, the benzene fraction of TOG varies depending on control technology (e.g., type of catalyst) and the levels of benzene and other aromatics in the fuel, but is generally higher than for diesel engines, about three to five percent. The benzene fraction of evaporative emissions from gasoline vehicles depends on control technology and fuel composition and characteristics (e.g., benzene level and the evaporation rate) and is generally about one percent.[175]

Nonroad engines account for 28 percent of nationwide emissions of benzene with nonroad diesel accounting for about 3 percent in 1996. Mobile sources as a whole account for 78 percent of the total benzene emissions in the nation. Nonroad sources as a whole account for an average of about 17 percent of ambient benzene in urban areas and about 9 percent of ambient benzene in rural areas across the U.S, in the 1996 NATA assessment. Of ambient benzene levels due to mobile sources, 5 percent in urban and 3 percent in rural areas come from nonroad diesel engines (see Figure 2.2.2-3).

Figure 2.2.2-3
Contribution of Source Sectors to Total Average
Nationwide Mobile Source Ambient Concentrations in 1996



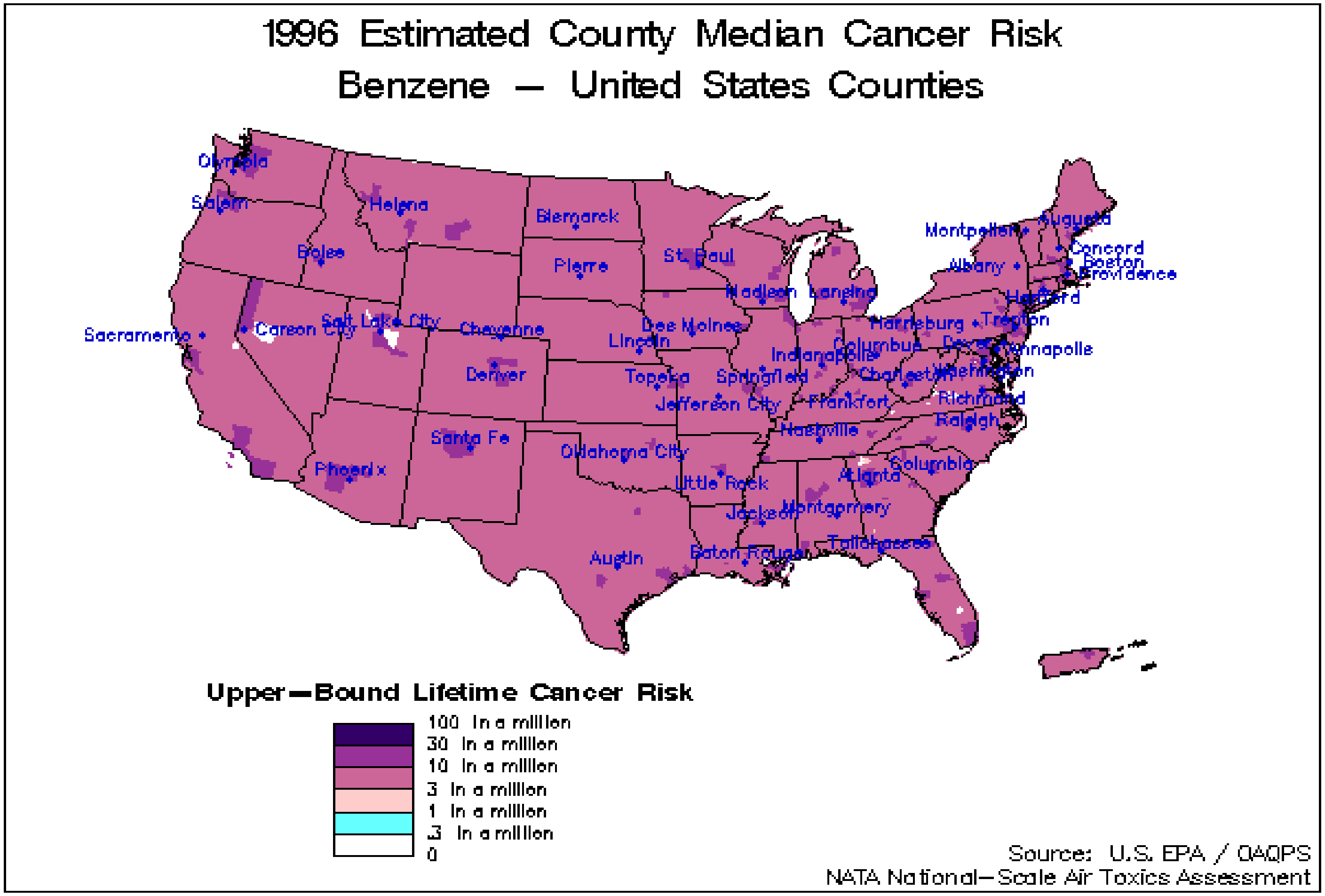
The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia at high, prolonged air exposures) by all routes of exposure.[176] It is associated with additional health effects including genetic changes in humans and animals and increased proliferation of bone marrow cells in mice.[177, 178] EPA states in its IRIS database that the data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. Respiration is the major source of human exposure and at least half of this exposure is attributable to gasoline vapors and automotive emissions. A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with low-dose, long-term exposure to benzene.

Respiration is the major source of human exposure to benzene. Long-term respiratory exposure to high levels of ambient benzene concentrations has been shown to cause cancer of the tissues that form white blood cells. Among these are acute nonlymphocytic leukemia,[H] chronic lymphocytic leukemia and possibly multiple myeloma (primary malignant tumors in the bone marrow), although the evidence for the latter has decreased with more recent studies.[179,180] Leukemias, lymphomas, and other tumor types have been observed in experimental animals exposed to benzene by inhalation or oral administration. Exposure to benzene and/or its metabolites has also been linked with genetic changes in humans and animals[181] and increased proliferation of mouse bone marrow cells.[182] The occurrence of certain chromosomal changes in individuals with known exposure to benzene may serve as a marker for those at risk for contracting leukemia.[183]

The latest assessment by EPA places the excess risk of developing acute nonlymphocytic leukemia at 2.2×10^{-6} to $7.7 \times 10^{-6}/\mu g/m^3$. In other words, there is a risk of about two to eight excess acute nonlymphocytic leukemia cases in one million people exposed to 1 $\mu g/m^3$ over a lifetime (70 years).[184] This range of unit risk represents the maximum likelihood estimate of risk. Figure 2.2.2-4 depicts the distribution of upper bound lifetime cancer risk from inhalation of benzene from ambient sources, based on average population exposure, from the 1996 NATA Assessment. Upper bound cancer risk is above 10 in a million across the entire U.S. EPA projects a median nationwide reduction in ambient concentrations of benzene from mobile sources of about 46percent between 1996 and 2007, as a result of current and planned control programs based on the analysis referenced earlier examining these pollutants in the 1996 to 2007 time frame based on the analysis of hazardous air pollutants in the 1996 to 2007 time frame referenced earlier.

[H] Leukemia is a blood disease in which the white blood cells are abnormal in type or number. Leukemia may be divided into nonlymphocytic (granulocytic) leukemias and lymphocytic leukemias. Nonlymphocytic leukemia generally involves the types of white blood cells (leukocytes) that are involved in engulfing, killing, and digesting bacteria and other parasites (phagocytosis) as well as releasing chemicals involved in allergic and immune responses. This type of leukemia may also involve erythroblastic cell types (immature red blood cells). Lymphocytic leukemia involves the lymphocyte type of white bloods cell that are responsible for the immune responses. Both nonlymphocytic and lymphocytic leukemia may, in turn, be separated into acute (rapid and fatal) and chronic (lingering, lasting) forms. For example; in acute myeloid leukemia (AML) there is diminished production of normal red blood cells (erythrocytes), granulocytes, and platelets (control clotting) which leads to death by anemia, infection, or hemorrhage. These events can be rapid. In chronic myeloid leukemia (CML) the leukemic cells retain the ability to differentiate (i.e., be responsive to stimulatory factors) and perform function; later there is a loss of the ability to respond.

Figure 2.2.2-4
Distribution of Upper Bound Lifetime Cancer Risk from Inhalation of Benzene from Ambient Sources, Based on Average Population Exposure



Source: 1996 NATA Assessment.

A number of adverse noncancer health effects, blood disorders such as preleukemia and aplastic anemia, have also been associated with low-dose, long-term exposure to benzene.[185, 186] People with long-term exposure to benzene may experience harmful effects on the blood-forming tissues, especially the bone marrow. These effects can disrupt normal blood production and cause a decrease in important blood components, such as red blood cells and blood platelets, leading to anemia (a reduction in the number of red blood cells), leukopenia (a reduction in the number of white blood cells), or thrombocytopenia (a reduction in the number of blood platelets, thus reducing the ability for blood to clot). Chronic inhalation exposure to benzene in humans and animals results in pancytopenia,[I] a condition characterized by decreased numbers of circulating erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (blood platelets).[187,188] Individuals that develop pancytopenia and have continued exposure to benzene may develop aplastic anemia,[J] whereas others exhibit both pancytopenia and bone marrow hyperplasia (excessive cell formation), a condition that may indicate a preleukemic state.[189] [190] The most sensitive noncancer effect observed in humans is the depression of absolute lymphocyte counts in the circulating blood.[191]

2.2.2.2 1,3-Butadiene

1,3-Butadiene is formed in engine exhaust by the incomplete combustion of fuel. It is not present in engine evaporative emissions, because it is not present in any appreciable amount in fuel. 1,3-Butadiene accounts for less than one percent of total organic gas exhaust from mobile sources.

Nonroad engines account for 18 percent of nationwide emissions of 1,3-butadiene in 1996 with nonroad diesel accounting for about 1.5 percent based on the NATA, NTI, and supplemental information already discussed in the previous section. Mobile sources account for 63 percent of the total 1,3-butadiene emissions in the nation as a whole. Nonroad sources as a whole account for an average of about 21 percent of ambient butadiene in urban areas and about 13 percent of ambient 1,3-butadiene in rural areas across the U.S. Of ambient butadiene levels due to mobile

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[I] Pancytopenia is the reduction in the number of all three major types of blood cells (erythrocytes, or red blood cells, thrombocytes, or platelets, and leukocytes, or white blood cells). In adults, all three major types of blood cells are produced in the bone marrow of the vertebra, sternum, ribs, and pelvis. The bone marrow contains immature cells, known as multipotent myeloid stem cells, that later differentiate into the various mature blood cells. Pancytopenia results from a reduction in the ability of the red bone marrow to produce adequate numbers of these mature blood cells.

[J] Aplastic anemia is a more severe blood disease and occurs when the bone marrow ceases to function, i.e.,these stem cells never reach maturity. The depression in bone marrow function occurs in two stages - hyperplasia, or increased synthesis of blood cell elements, followed by hypoplasia, or decreased synthesis. As the disease progresses, the bone marrow decreases functioning. This myeloplastic dysplasia (formation of abnormal tissue) without acute leukemias known as preleukemia. The aplastic anemia can progress to AML (acute mylogenous leukemia).

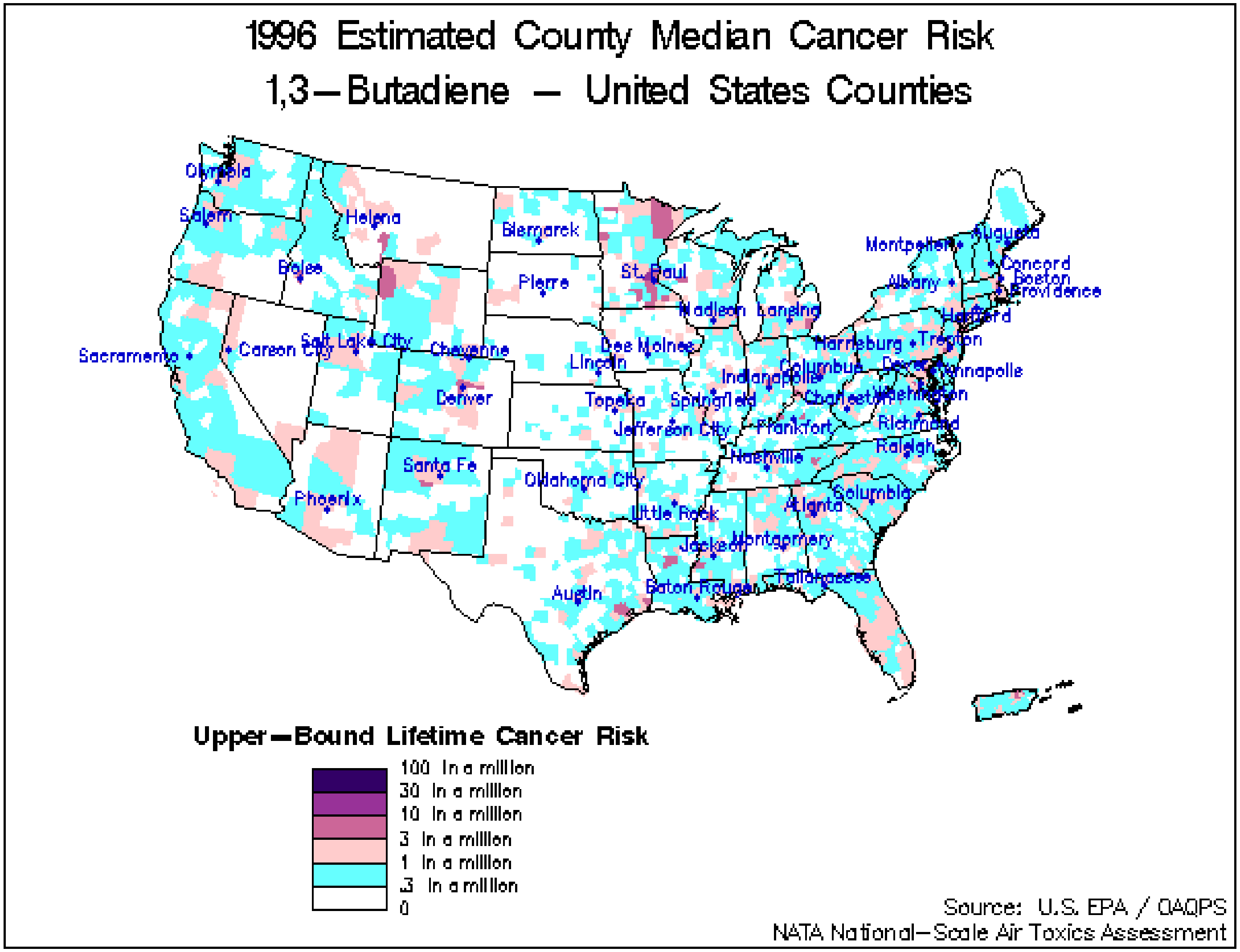
sources, 4 percent in urban and 2 percent in rural areas come from nonroad diesel (see Figure 2.2.2-3).

EPA earlier identified 1,3-butadiene as a probable human carcinogen in its IRIS database.[192] Recently EPA redesignated 1,3-butadiene as a known human carcinogen.[193,194,195] The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown. However, it is virtually certain that the carcinogenic effects are mediated by genotoxic metabolites of 1,3-butadiene. Animal data suggest that females may be more sensitive than males for cancer effects; but more data are needed before reaching definitive conclusions on potentially sensitive subpopulations.

The unit cancer risk estimate is 0.08/ppm or 3x10-5 per µg/m3 (based primarily on linear modeling and extrapolation of human data). In other words, it is estimated that approximately 30 persons in one million exposed to 1 µg/m^3 1,3-butadiene continuously for their lifetime (70 years) would develop cancer as a result of this exposure. The human incremental lifetime unit cancer risk (incidence) estimate is based on extrapolation from leukemias observed in an occupational epidemiologic study.[196] A twofold adjustment to the epidemiologic-based unit cancer risk was applied to reflect evidence from the rodent bioassays suggesting that the epidemiologic-based estimate may underestimate total cancer risk from 1,3-butadiene exposure in the general population. Figure 2.2.2-5 depicts the distribution of upper bound lifetime cancer risk from inhalation of 1,3-butadiene from ambient sources, based on average population exposure, from the 1996 NATA Assessment. Upper bound cancer risk is above 10 in a million across the entire U.S. EPA projects a median nationwide reduction in ambient concentrations of benzene from mobile sources of about 46 percent between 1996 and 2007, as a result of current and planned control programs.

1,3-Butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[197] Based on this critical effect and the benchmark concentration methodology, an RfC (i.e., a chronic exposure level presumed to be “without appreciable risk” for noncancer effects) was calculated. This RfC for chronic health effects was 0.9 ppb.

Figure 2.2.2-5
Distribution of Upper Bound Lifetime Cancer Risk from
Inhalation of 1,3-Butadiene from Ambient Sources, Based on Average Population Exposure



Source: 1996 NATA Assessment.

2.2.2.3 Formaldehyde

Formaldehyde is the most prevalent aldehyde in engine exhaust. It is formed from incomplete combustion of both gasoline and diesel fuel. In a recent test program which measured toxic emissions from several nonroad diesel engines, ranging from 50 to 480 horsepower, formaldehyde consistently accounted for well over 10 percent of total exhaust hydrocarbon emissions.[198] Formaldehyde accounts for far less of total exhaust hydrocarbon emissions from gasoline engines, although the amount can vary substantially by duty cycle, emission control system, and fuel composition. It is not found in evaporative emissions.

Nonroad engines account for 29 percent of nationwide emissions of formaldehyde in 1996, with nonroad diesel accounting for about 22 percent based on the NATA, NTI, and supplemental information already discussed. Mobile sources as a whole account for 56 percent of the total formaldehyde emissions in the nation. Of ambient formaldehyde levels due to mobile sources, 37 percent in urban and 27 percent in rural areas come from nonroad diesel. Nonroad sources as a whole account for an average of about 41 percent of ambient formaldehyde in urban areas and about 10 percent of ambient formaldehyde in rural areas across the U.S, in the 1996 NATA assessment. These figures are for tailpipe emissions of formaldehyde. Formaldehyde in the ambient air comes not only from tailpipe (of direct) emissions but is also formed from photochemical reactions of hydrocarbons. Mobile sources are responsible for well over 50 percent of total formaldehyde including both the direct emissions and photochemically formed formaldehyde in the ambient air, according to the NATA for 1996.

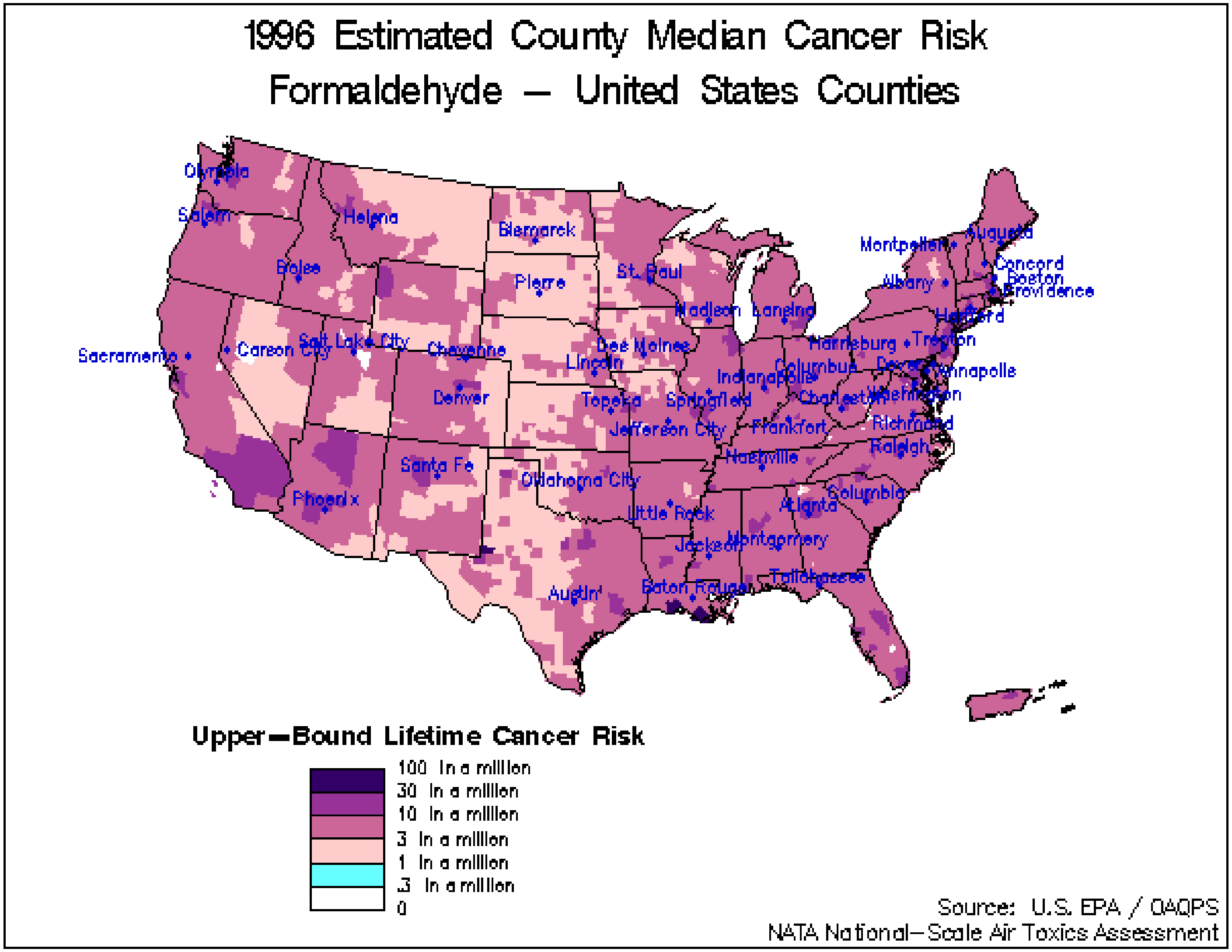
EPA has classified formaldehyde as a probable human carcinogen based on limited evidence for carcinogenicity in humans and sufficient evidence of carcinogenicity in animal studies, rats, mice, hamsters, and monkeys.[199, 200] Epidemiological studies in occupationally exposed workers suggest that long-term inhalation of formaldehyde may be associated with tumors of the nasopharyngeal cavity (generally the area at the back of the mouth near the nose), nasal cavity, and sinus.[201] Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to formaldehyde causes an increase in the incidence of squamous (epithelial) cell carcinomas (tumors) of the nasal cavity.[202, 203, 204] The distribution of nasal tumors in rats suggests that not only regional exposure but also local tissue susceptibility may be important for the distribution of formaldehyde-induced tumors.[205] Research has demonstrated that formaldehyde produces mutagenic activity in cell cultures.[206]

The upper confidence limit estimate of a lifetime extra cancer risk from continuous formaldehyde exposure is about $1.3 \times 10^{-5}/\mu g/m^3$. In other words, it is estimated that approximately 10 persons in one million exposed to 1 $\mu g/m^3$ formaldehyde continuously for their lifetime (70 years) would develop cancer as a result of this exposure. The agency is currently conducting a reassessment of risk from inhalation exposure to formaldehyde based on new information including a study by the Chemistry Industry Institute of Toxicology.[207, 208] Figure 2.2.2-6 depicts the distribution of upper bound lifetime cancer risk from inhalation of formaldehyde from ambient sources, based on the current unit risk and average population exposure from the 1996 NATA Assessment. Upper bound cancer risk is above 10 in a million for more than one hundred million Americans. EPA projects a median nationwide reduction in ambient concentrations of benzene from mobile sources of about 43 percent between 1996 and 2007, as a result of current and planned control programs (Cook et al., 2002).

Formaldehyde exposure also causes a range of noncancer health effects. At low concentrations (e.g. 0.05-2.0 ppm), irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes is the principal effect observed in humans. At exposure to 1-11 ppm, other human upper respiratory effects associated with acute formaldehyde exposure include a dry or sore throat, and a tingling sensation of the nose. Sensitive individuals may experience these effects at lower concentrations. Forty percent of formaldehyde-producing factory workers reported nasal symptoms such as rhinitis (inflammation of the nasal membrane), nasal obstruction, and nasal discharge following chronic exposure.[209] In persons with bronchial asthma, the upper respiratory irritation caused by formaldehyde can precipitate an acute asthmatic attack, sometimes at concentrations below 5 ppm.[210] Formaldehyde exposure may also cause bronchial asthma-like symptoms in non-asthmatics.[211] [212]

Immune stimulation may occur following formaldehyde exposure, although conclusive evidence is not available. Also, little is known about formaldehyde's effect on the central nervous system. Several animal inhalation studies have been conducted to assess the developmental toxicity of formaldehyde: The only exposure-related effect noted in these studies was decreased maternal body weight gain at the high-exposure level. No adverse effects on reproductive outcome of the fetuses that could be attributed to treatment were noted. An inhalation reference concentration (RfC), below which long-term exposures would not pose appreciable noncancer health risks, is not available for formaldehyde at this time. The Agency is currently conducting a reassessment of risk from inhalation exposure to formaldehyde.

Figure 2.2.2-6
Distribution of Upper Bound Lifetime Cancer Risk from Inhalation
of 1,3-Butadiene from Ambient Sources, Based on Average Population Exposure



Source: 1996 NATA Assessment.

2.2.2.4 Acetaldehyde

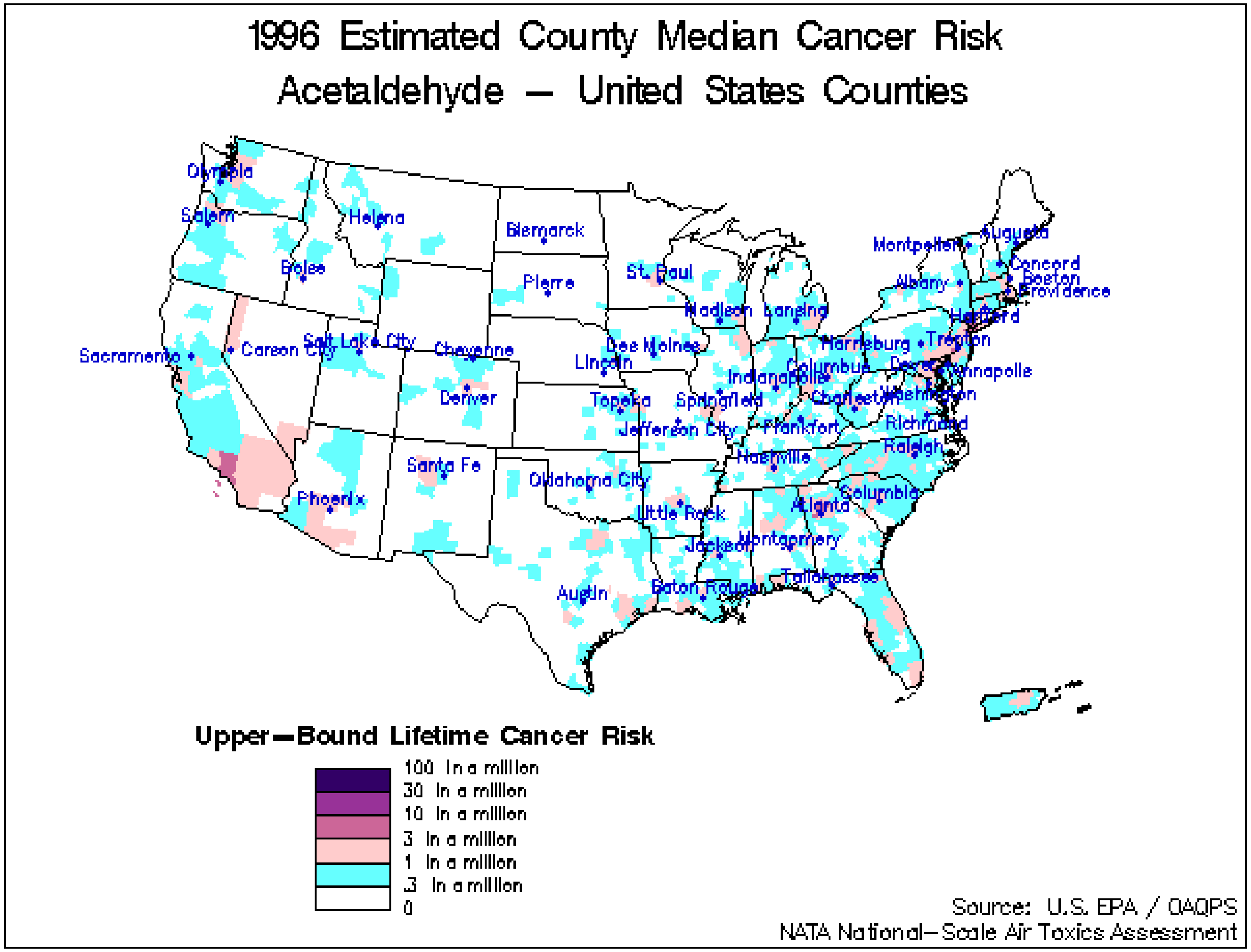
Acetaldehyde is a saturated aldehyde that is found in engine exhaust and is formed as a result of incomplete combustion of both gasoline and diesel fuel. In a recent test program which measured toxic emissions from several nonroad diesel engines, ranging from 50 to 480 horsepower, acetaldehyde consistently accounted for over 5 percent of total exhaust hydrocarbon emissions (Southwest Research, 2002). Acetaldehyde accounts for far less of total exhaust hydrocarbon emissions from gasoline engines, although the amount can vary substantially by duty cycle, emission control system, and fuel composition. It is not a component of evaporative emissions.

Nonroad engines account for 43 percent of nationwide emissions of acetaldehyde with nonroad diesel accounting for about 34 percent based on the NATA, NTI, and supplemental information. Mobile sources as a whole account for 73 percent of the total acetaldehyde emissions in the nation. Nonroad sources as a whole account for an average of about 36 percent of ambient acetaldehyde in urban areas and about 21 percent of ambient acetaldehyde in rural areas across the U.S, in the 1996 NATA assessment. Of ambient acetaldehyde levels due to mobile sources, 24 percent in urban and 17 percent in rural areas come form nonroad diesel.. Also, acetaldehyde can be formed photochemically in the atmosphere. Counting both direct emissions and photochemically formed acetaldehyde, mobile sources are responsible for the major portion of acetaldehyde in the ambient air according to the NATA for 1996.

Acetaldehyde is classified as a probable human carcinogen. Studies in experimental animals provide sufficient evidence that long-term inhalation exposure to acetaldehyde causes an increase in the incidence of nasal squamous cell carcinomas (epithelial tissue) and adenocarcinomas (glandular tissue).[213, 214, 215, 216, 217] The upper confidence limit estimate of a lifetime extra cancer risk from continuous acetaldehyde exposure is about 2.2×10^{-6} /µg/m^3. In other words, it is estimated that about 2 persons in one million exposed to 1 µg/m^3 acetaldehyde continuously for their lifetime (70 years) would develop cancer as a result of their exposure. The Agency is currently conducting a reassessment of risk from inhalation exposure to acetaldehyde. Figure 2.2.2-7 depicts the distribution of upper bound lifetime cancer risk from inhalation of formaldehyde from ambient sources, based on the current unit risk and average population exposure from the 1996 NATA. Upper bound cancer risk is above one in a million for more than one hundred million Americans. EPA projects a median nationwide reduction in ambient concentrations of benzene from mobile sources of about 36 percent between 1996 and 2007, as a result of current and planned control programs

EPA's IRIS database states that noncancer effects in studies with rats and mice showed acetaldehyde to be moderately toxic by the inhalation, oral, and intravenous routes (EPA, 1988). Similar conclusions have been made by the California Air Resources Board.[218] The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract. At high concentrations, irritation and pulmonary effects can occur, which could facilitate the uptake of other contaminants. Little research exists that addresses the effects of inhalation of

Figure 2.2.2-7
Distribution of Upper Bound Lifetime Cancer Risk from Inhalation of
Acetaldehyde from Ambient Sources, Based on Average Population Exposure



1996 Estimated County Median Cancer Risk
Acetaldehyde — United States Counties

Source: U.S. EPA / OAQPS
NATA National-Scale Air Toxics Assessment

Source: 1996 NATA Assessment.

acetaldehyde on reproductive and developmental effects. The in vitro and in vivo studies provide evidence to suggest that acetaldehyde may be the causative factor in birth defects observed in fetal alcohol syndrome, though evidence is very limited linking these effects to inhalation exposure. Long-term exposures should be kept below the reference concentration of 9 µg/m^3 to avoid appreciable risk of these noncancer health effects (EPA, 1988).

Acetaldehyde has been associated with lung function decrements in asthmatics. In one study, aerosolized acetaldehyde caused reductions in lung function and bronchoconstriction in asthmatic subjects.[219]

2.2.2.5 Acrolein

In a recent test program which measured toxic emissions from several nonroad diesel engines, ranging from 50 to 480 horsepower, acrolein accounted for about 0.5 to 2 percent of total exhaust hydrocarbon emissions (Southwest Research, 2002). Acrolein accounts for far less of total exhaust hydrocarbon emissions from gasoline engines, although the amount can vary substantially by duty cycle, emission control system, and fuel composition. It is not a component of evaporative emissions.

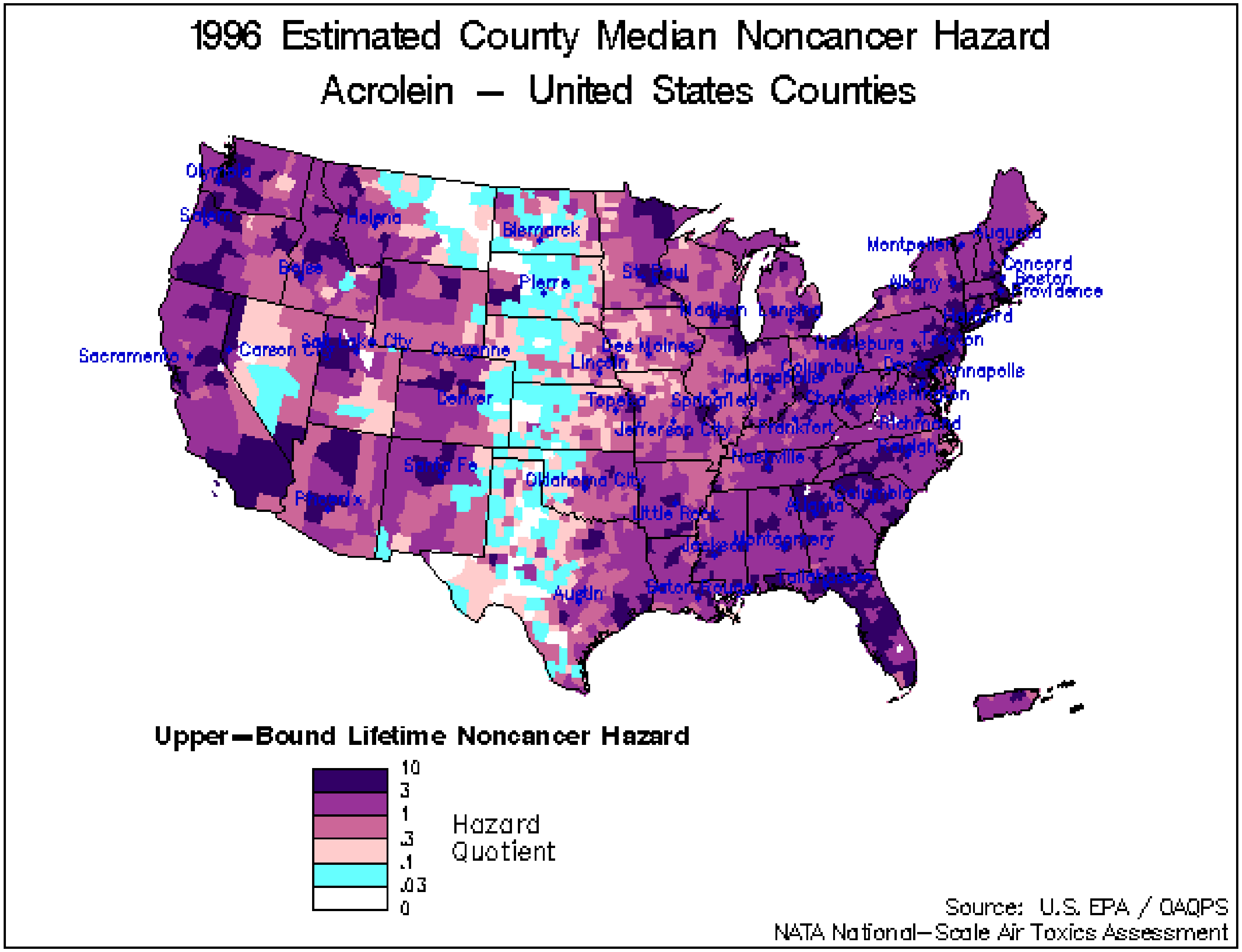
Nonroad engines account for 25 percent of nationwide emissions of acetaldehyde in 1996 with nonroad diesel accounting for about 17.5 percent based on NATA, NTI, and the supplemental information Mobile sources as a whole account for 43 percent of the total acrolein emissions in the nation. Of ambient acrolein levels due to mobile sources, 28 percent in urban and 18 percent in rural areas come form nonroad diesel according to NATA.

Acrolein is extremely toxic to humans from the inhalation route of exposure, with acute exposure resulting in upper respiratory tract irritation and congestion. The Agency developed a reference concentration for inhalation (RfC) of acrolein of 0.02 µg/m^3 in 1993. Figure 2.2.2-8 depicts the distribution of hazard quotients for acrolein across the U.S.[K] The hazard quotient is greater than one for most of the U.S. population, indicating a potential for adverse noncancer health effects.

Although no information is available on its carcinogenic effects in humans, based on laboratory animal data, EPA considers acrolein a possible human carcinogen.[220]

[K] The hazard quotient is the ratio of average ambient exposure over the reference concentration (level below which adverse health effects are not expected to occur). A hazard quotient above one indicates the potential for adverse health effects, but does not necessarily mean adverse health effects will occur.

Figure 2.2.2-8
Distribution of Noncancer Hazard Quotients for Inhalation
of Acrolein from Ambient Sources, Based on Average Population Exposure



Source: U.S. EPA / OAQPS
NATA National-Scale Air Toxics Assessment

Source: 1996 NATA Assessment.

2.2.2.6 Polycyclic Organic Matter

POM is generally defined as a large class of chemicals consisting of organic compounds having multiple benzene rings and a boiling point greater than 100 degrees C. Polycyclic aromatic hydrocarbons (PAHs) are a chemical class that is a subset of POM. POM are naturally occurring substances that are byproducts of the incomplete combustion of fossil fuels and plant and animal biomass (e.g., forest fires). They occur as byproducts from steel and coke productions and waste incineration. They also are a component of diesel PM emissions. As mentioned in Section 2.1.2.1.2, many of the compounds included in the class of compounds known as POM are classified by EPA as probable human carcinogens based on animal data. In particular, EPA obtained data on 7 of the POM compounds, which we analyzed separately as a class in the NATA for 1996. Nonroad engines account for only 1 percent of these 7 POM compounds with total mobile sources responsible for only 4 percent of the total; most of the 7 POMs come from area sources. For total POM compounds, mobile sources as a whole are responsible for only 1 percent. The mobile source emission numbers used to derive these inventories are based on only particulate phase POM and do not include the semi-volatile phase POM levels. Were those additional POMs included (which is now being done in the NATA for 1999), these inventory numbers would be substantially higher. A study of indoor PAH found that concentrations of indoor PAHs followed the a similar trend as outdoor motor traffic, and that motor vehicle traffic was the largest outdoor source of PAH.[221]

A recent study found that maternal exposures to polycyclic aromatic hydrocarbons (PAHs) in a multiethnic population of pregnant women were associated with adverse birth outcomes, including low birth weight, low birth length, and reduced head circumference.[222]

2.2.2.7 Dioxins

Recent studies have confirmed that dioxins are formed by and emitted from diesels (both heavy-duty diesel trucks and non-road diesels although in very small amounts) and are estimated to account for about 1 percent of total dioxin emissions in 1995. Recently EPA issued a draft assessment designating one dioxin compound, 2,3,7,8-tetrachlorodibenzo-p-dioxin as a human carcinogen and the complex mixtures of dioxin-like compounds as likely to be carcinogenic to humans using the draft 1996 carcinogen risk assessment guidelines. EPA is working on its final assessment for dioxin.[223] An interagency review group is evaluating EPA's designation of dioxin as a likely human carcinogen. These nonroad rules will have minimal impact on overall dioxin emissions.

2.3 Ozone

This section reviews health and welfare effects of ozone and describes the air quality information that forms the basis of our conclusion that ozone concentrations in many areas across the country face a significant risk of exceeding the ozone standard into the year 2030.

Information on air quality was gathered from a variety of sources, including monitored ozone concentrations from 1999-2001, air quality modeling forecasts conducted for this rulemaking and other state and local air quality information.

Ground-level ozone, the main ingredient in smog, is formed by the reaction of volatile organic compounds (VOCs) and nitrogen oxides (NOx) in the atmosphere in the presence of heat and sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources, including on-highway and nonroad motor vehicles and engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller "area" sources. VOCs are also emitted by natural sources such as vegetation. Oxides of nitrogen are emitted largely from motor vehicles, off-highway equipment, power plants, and other sources of combustion.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NOx, VOC, heat, and sunlight. Many of the chemical reactions that are part of the ozone-forming cycle are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and produce more ozone than typically would occur on a single high temperature day. Further complicating matters, ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low VOC or NOx emissions. As a result, differences in NOx and VOC emissions and weather patterns contribute to daily, seasonal, and yearly differences in ozone concentrations and differences from city to city.

These complexities also have implications for programs to reduce ozone. For example, relatively small amounts of NOx enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NOx. Under these conditions, NOx reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NOx-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NOx-limited.

When NOx levels are relatively high and VOC levels relatively low, NOx forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited." Under these conditions, VOC reductions are effective in reducing ozone, but NOx reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NOx reductions are not expected to increase ozone levels if the NOx reductions are sufficiently large. The highest levels of ozone are produced when both VOC and NOx emissions are present in significant quantities on clear summer days.

Rural areas are almost always NOx-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NOx-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NOx, VOC, and ozone, all of which change with time and location.

2.3.1 Health Effects of Ozone

Exposure to ambient ozone contributes to a wide range of adverse health effects, which are discussed in detail in the EPA Air Quality Criteria Document for Ozone.[224] Effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased medication usage, inflammation of the lungs, as well as a variety of other respiratory effects. People who are particularly at risk for high ozone exposures inclue healthy children and adults who are active outdoors. Susceptible subgroups include children, people with respiratory disease, such as asthma, and people with unusual sensitivity to ozone. More information on health effects of ozone is also available at http:/www.epa.gov/ttn/naaqs/standards/ozone/s.03.index.html.

Based on a large number of scientific studies, EPA has identified several key health effects caused when people are exposed to levels of ozone found today in many areas of the country. Short-term (1 to3 hours) and prolonged exposures (6 to 8 hours) to higher ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[225, 226, 227, 228, 229, 230] Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[231, 232, 233, 234, 235] It also can cause inflammation of the lung, impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could lead to premature aging of the lungs and/or chronic respiratory illnesses, such as emphysema and chronic bronchitis.[236, 237, 238, 239]

Adults who are outdoors and active during the summer months, such as construction workers and other outdoor workers, also are among those most at risk of elevated exposures.[240] Thus, it may be that children and outdoor workers are most at risk from ozone exposure because they typically are active outside, playing and exercising, during the summer when ozone levels are highest.[241, 242] For example, summer camp studies in the Eastern U.S. and southeastern Canada have reported significant reductions in lung function in children who are active outdoors.[243, 244, 245, 246, 247, 248, 249, 250] Further, children are more at risk of experiencing health effects than adults from ozone exposure because their respiratory systems are still developing. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.[251, 252, 253, 254]

The 8-hour NAAQS is based on well-documented science demonstrating that more people are experiencing adverse health effects at lower levels of exertion, over longer periods, and at lower ozone concentrations than addressed by the 1-hour ozone standard.[255] Attaining the 8-hour standard greatly limits ozone exposures of concern for the general population and populations most at risk, including children active outdoors, outdoor workers, and individuals with pre-existing respiratory disease, such as asthma.

There has been new research that suggests additional serious health effects beyond those that had been know when the 8-hour ozone standard was set. Since 1997, over 1,700 new health and welfare studies have been published in peer-reviewed journals.[256] Many of these studies have investigated the impact of ozone exposure on such health effects as changes in lung structure and biochemistry, inflammation of the lungs, exacerbation and causation of asthma, respiratory illness-related school absence, hospital and emergency room visits for asthma and other respiratory causes, and premature mortality. EPA is currently in the process of evaluating these and other studies as part of the ongoing review of the air quality criteria and NAAQS for ozone. A revised Air Quality Criteria Document for Ozone and Other Photochemical Oxidants will be prepared in consultation with the EPA's Clean Air Scientific Advisory Committee (CASAC).

Key new health information falls into four general areas: development of new-onset asthma, hospital admissions for young children, school absence rate, and premature mortality. Examples of new studies in these areas are briefly discussed below.

Aggravation of existing asthma resulting from short-term ambient ozone exposure was reported prior to the 1997 decision and has been observed in studies published since.[257, 258] More recent studies now suggest a relationship between long-term ambient ozone concentrations and the incidence of new-onset asthma. In particular, such a relationship in adult males (but not in females) was reported by McDonnell et al. (1999).[259] Subsequently, McConnell et al. (2002) reported that incidence of new diagnoses of asthma in children is associated with heavy exercise in communities with high concentrations (i.e., mean 8-hour concentration of 59.6 ppb) of ozone.[260] This relationship was documented in children who played 3 or more sports and was not statistically significant for those children who played one or two sports.[L] The larger effect of high activity sports than low activity sports and an independent effect of time spent outdoors also in the higher ozone communities strengthened the inference that exposure to ozone may modify the effect of sports on the development of asthma in some children.

Previous studies have shown relationships between ozone and hospital admissions in the general population. A new study in Toronto reported a significant relationship between 1-hour maximum ozone concentrations and respiratory hospital admissions in children under two.[261] Given the relative vulnerability of children in this age category, we are particularly concerned about the findings from the literature on ozone and hospital admissions.

Increased respiratory disease that are serious enough to cause school absences has been associated with 1-hour daily maximum and 8-hour average ozone concentrations in studies

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[L] In communities with high ozone (i.e., mean 8-hour concentration of 59.6 ppb) the relative risk of developing asthma in children playing three or more sports was 3.3. (95% CI 1.9 - 5.8) compared with children playing no sports.

conducted in Nevada in kindergarten to 6th grade [262] and in Southern California in grades 4 to 6.[263] These studies suggest that higher ambient ozone levels may result in increased school absenteeism.

The ambient air pollutant most clearly associated with premature mortality is PM, with dozens of studies reporting such an association. However, repeated ozone exposure may be a contributing factor for premature mortality, causing an inflammatory response in the lungs which may predispose elderly and other sensitive individuals to become more susceptible to the adverse health effects of other air pollutants, such as PM.[264, 265] Although the findings in the past have been mixed, the findings of three recent analyses suggests that ozone exposure is associated with increased mortality. Although the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) did not find an effect of ozone on total mortality across the full year, Samet et al. (2000), who conducted the NMMAPS study, did report an effect after limiting the analysis to summer when ozone levels are highest.[266] Similarly, Thurston and Ito (1999) have reported associations between ozone and mortality.[267] Toulomi et al., (1997) reported that 1-hour maximum ozone levels were associated with daily numbers of deaths in 4 cities (London, Athens, Barcelona, and Paris), and a quantitatively similar effect was found in a group of 4 additional cities (Amsterdam, Basel, Geneva, and Zurich).[268]

As discussed in Section 2.1 with respect to PM studies, the Health Effects Institute (HEI) reported findings by health researchers that have raised concerns about aspects of the statistical methodology used in a number of recent time-series studies of short-term exposures to air pollution and health effects.[269]

2.3.2 Attainment and Maintenance of the 1-Hour and 8-Hour Ozone NAAQS

As shown earlier in Figure 2-1, unhealthy ozone concentrations – i.e., those exceeding the level of the 8-hour standard which is requiste to protect public health with an adequate margin of safety – occur over wide geographic areas, including most of the nation's major population centers. These areas include much of the eastern half of the U.S. and large areas of California. Nonroad engines contribute a substantial fraction of ozone precursors in metropolitan areas.

In presenting these values, we examine concentrations in counties as well as calculating design values. An ozone design value is the concentration that determines whether a monitoring site meets the NAAQS for ozone. Because of the way they are defined, design values are determined based on 3 consecutive-year monitoring periods. For example, an 8-hour design value is the fourth highest daily maximum 8-hour average ozone concentration measured over a three-year period at a given monitor. The full details of these determinations (including accounting for missing values and other complexities) are given in Appendices H and I of 40 CFR Part 50. As discussed in these appendices, design values are truncated to whole part per billion (ppb). Due to the precision with which the standards are expressed (0.08 parts per million (ppm) for the 8-hour), a violation of the 8-hour standard is defined as a design value greater than or equal to 0.085 ppm. Thus, we follow this convention in these analyses.

For a county, the design value is the highest design value from among all the monitors with valid design values within that county. If a county does not contain an ozone monitor, it does not have a design value. Thus, our analysis may underestimate the number of counties with design values above the level of NAAQS. For the purposes of defining the current design value of a given area, the 1999-2001 design values were chosen to provide the most recent set of air quality data for identifying areas likely to have an ozone problem in the future. The1999-2001 design values are listed in the AQ TSD, which is available in the docket to this rule.

2.3.2.1 1-Hour Ozone Nonattainment Areas and Concentrations

Currently, there are 116 million people living in 56 1-hour ozone nonattainment areas covering 233 counties. Of these, there are 1 extreme and 10 severe 1-hour ozone nonattainment areas with a total affected population of 86.5 million as shown in Table 2.3-1. We focus on these designated areas because the timing of their attainment dates relates to the timing of the proposed reductions. Five severe 1-hour ozone nonattainment areas have attainment dates of December 31, 2007. While all of these areas are expected to be in attainment before the emission reductions from this proposed rule are expected to occur, these reductions will be important to assist these areas in maintaining the standards. The Los Angeles South Coast Air Basin is designated as an extreme nonattainment area and has a compliance date of December 31, 2010. The reductions from this rule will be an important part of their overall strategy to attain and maintain the standard.

Table 2.3-1
1-Hour Ozone Extreme and Severe Nonattainment Areas

Nonattainment Area	Attainment Date	2000 Population (millions)	1999-2001 Measured Violation?
Los Angeles South Coast Air Basin, CA[a]	December 31, 2010[a]	14.6	Yes
Chicago-Gary-Lake County, IL-IN	December 31, 2007	8.9	No
Houston-Galveston-Brazoria, TX	December 31, 2007	4.5	Yes
Milwaukee-Racine, WI	December 31, 2007	1.7	No
New York-New Jersey-Long Island, NY-NJ-CT	December 31, 2007	20.2	Yes
Southeast Desert Modified AQMA, CA	December 31, 2007	0.5	Yes
Baltimore, MD	2005	0.8	Yes
Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD	2005	6.0	Yes
Sacramento, CA	2005	1.2	Yes
San Joaquin Valley, CA	2005	7.8	Yes
Ventura County, CA	2005	0.1	Yes
Total Population	86.5 million		

[a] Extreme 1-Hour nonattainment areas. All other areas are severe nonattainment areas.

The extreme nonattainment area will need additional reductions to attain the ozone standard and will also be able to rely on additional reductions from today's proposed action in order to maintain the standard. The severe areas will be able to rely on the reductions from today's proposed action in order to maintain the standard.

The emission reductions from this proposed rule would also help these areas reach attainment at lower overall cost, with less impact on small businesses, as discussed in other chapters of this document. Following implementation of controls for regional NOx reductions, States will have already adopted emission reduction requirements for most large sources of NOx for which cost-effective control technologies are known and for which they have authority to control. Those that must adopt measures to complete their attainment demonstrations and maintenance plans, therefore, will have to consider their remaining alternatives. Many of the alternatives that areas may consider could be more costly, and the NOx emissions impact from each additional emissions source subjected to new emissions controls could be considerably smaller than the emissions impact of the standards being proposed today. Therefore, the emission reductions from the standards we are finalizing today will ease the need for States to find first-time reductions from the mostly smaller sources that have not yet been controlled, including area sources that are closely connected with individual and small business activities. The emission reductions from nonroad diesel engines also reduce the need for States to seek even deeper reductions from large and small sources already subject to emission controls.

Each of the areas in Table 2.3-1 is adopting additional measures to address specific emission reduction shortfalls in attainment SIPs submitted for New York, Houston, the South Coast Basin, Philadelphia, and Baltimore based on the local ozone modeling and other evidence. The San Joaquin Valley will need additional reductions to attain and maintain the standards. There is some risk that New York will fail to attain the standard by 2007, and thus a transferred risk that Connecticut will also fail. A similar situation exists in Southern California, where attainment of the South Coast is a precondition of the ability of downwind to reach attainment by their respective attainment dates. Additional reductions from this rule will assist New York and Greater Connecticut, and the South Coast and its downwind nonattainment areas, in reaching the standard by each areas' respective attainment dates and maintaining the standard in the future.

The Los Angeles (South Coast Air Basin) ozone attainment demonstration is fully approved, but it is based in part on reductions from new technology measures that have yet to be identified (as allowed under CAA Section 182(e)(5)). Thus, additional reductions would be helpful to this area, as discussed in the draft plan.[270] The 2007 attainment demonstration for the Southeast Desert area is also approved. However, a transport situation exists between the Southeast Desert areas and the South Coast Air Basin, such that attainment in the Southeast Desert depends on progress in reducing ozone levels in the South Coast Air Basin.

Even if the SIPs were approved and all shortfalls were filled in an area, there would still be a risk that ozone levels in such an area could exceed the NAAQS. EPA's approval of an attainment demonstration generally indicates our belief that a nonattainment area is reasonably likely to attain by the applicable attainment date with the emission controls in the SIP. However, such approval does not indicate that attainment is certain. Moreover, no ozone forecasting is 100 percent certain, so attainment by these deadlines is not certain, even though we believe it is more likely than not. There are significant uncertainties inherent in predicting future air quality, such as unexpected economic growth, unexpected vehicle miles traveled (VMT) growth, the year-to-year variability of meteorological conditions conducive to ozone formation, and modeling approximations. There is at least some risk in each of these areas that even assuming all shortfalls are filled, attainment will not be reached by the applicable dates without further emission reductions. The Agency's mid-course review in the SIP process—as well as the Clean Air Act's provisions for contingency measures—is part of our strategy for dealing with some of these uncertainties, but does not ensure successful attainment.

Many 1-hour ozone nonattainment areas continue to experience exceedances. Approximately 51 million people are living in counties with measured air quality violating the 1-hour NAAQS in 1999-2001.[M] See the AQ TSD for more details about the counties and populations experiencing various levels of measured 1-hour ozone concentrations.

The ability of states to maintain the ozone NAAQS once attainment is reached has proved challenging, and the recent recurrence of violations of the NAAQS in some other areas increases the Agency's concern about continuing maintenance of the standard. Recurrent nonattainment is especially problematic for areas where high population growth rates lead to significant annual increases in vehicle trips and VMT. Moreover, ozone modeling conducted for this proposed rule predicted exceedances in 2020 and 2030 (without additional controls), which adds to the Agency's uncertainty about the prospect of continued attainment for these areas. The reductions from today's proposed action will help areas to attain and maintain the 1-hour standards.

2.3.2.2 8-Hour Ozone Levels: Current and Future Concentrations

As described above in Section 2.3.1, the 8-hour NAAQS is based on well-documented science demonstrating that more people are experiencing adverse health effects at lower levels of exertion, over longer periods, and at lower ozone concentrations than addressed by the 1-hour ozone standard.[271] The 8-hour standard greatly limits ozone exposures of concern for the general population and sensitive populations. This section describes the current measured 8-hour concentrations and describes our modeling to predict future 8-hour ozone concentrations.

2.3.2.2.1 Current 8-Hour Ozone Concentrations

Based upon the measured data from years 1999 - 2001, there are 291 counties with measured values that violate the 8-hour ozone NAAQS, with a population totaling 111 million, as shown in Figure 2-1. Of these, 61 million people live in counties that meet the 1-hour standard but violate the 8-hour standard. There may be additional areas above the level of the NAAQS for which no monitoring data are available.

An additional 37 million people live in 155 counties that have air quality measurements within 10 percent of the level of the standard. These areas, though currently not violating the standard, will also benefit from the emission reductions from this proposed rule.

Approximately 48 million people lived in counties with at least a week (7 days) of 8-hour ozone concentrations measurements at or above 0.085 ppm in 2000. Approximately 8 million people lived in counties experiencing 20 days and 4 million experienced 40 days of 8-hour ozone concentrations at or above 0.085 ppm in 2000. See the AQ TSD for more details about the

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[M] Typically, county design values (and thus exceedances) are consolidated where possible into design values for consolidated metropolitan statistical areas (CMSA) or metropolitan statistical areas (MSA). Accordingly, the design value for a metropolitan area is the highest design value among the included counties, and counties that are not in metropolitan areas would be treated separately. However, for this section, we examined data on a county basis, not consolidating into CMSA or MSA. Designated nonattainment areas may contain more than one county, and some of these counties are experiencing recent exceedances, as indicated in the table. Further, the analysis is limited to areas with monitors.

counties and populations experiencing various levels of measured 8-hour ozone concentrations.

2.3.2.2.2 Risk of Future 8-Hour Ozone Violations

Our air quality modeling shows that there will continue to be a need for reductions in ozone concentrations in the future without additional controls. In this section we describe the air quality modeling including the non-emission inventory inputs. (See Chapter 3.6 summarizes the emission inventory inputs.) We then discuss the results of the modeling for baseline conditions absent additional control of nonroad diesel engines.

We have also used our air quality modeling to estimate the change in future ozone levels that would result from reductions in emissions from nonroad diesel engines. For this proposal, we modeled a preliminary control scenario which illustrates the likely reductions from our proposal. Because of the substantial lead time to prepare the complex air quality modeling analyses, it was necessary to develop a control options early in the process based on our best judgement at that time. As additional data regarding technical feasibility and other factors became available, our judgement about the controls that are feasible has evolved. Thus, the preliminary control option differs from what we are proposing, as summarized in Section 3.6 below.[N] It is important to note that these changes would not affect our estimates of the baseline conditions without additional controls from nonroad diesel engines. For the final rule, considering public comment, we plan to model the final control scenario. This proposed rule would produce nationwide air quality improvements in ozone levels, and we present the modeled improvements in this section. Those interested in greater detail should review the AQ Modeling TSD, which is available in the docket to this rule.

2.3.2.2.3 Ozone Modeling Methodology, Domains and Simulation Periods

In conjunction with this rulemaking, we performed a series of ozone air quality modeling simulations for the Eastern and Western U.S. using Comprehensive Air Quality Model with Extension (CAMx). The model simulations were performed for five emissions scenarios: a 1996 baseline projection, a 2020 baseline projection and a 2020 projection with nonroad controls, a 2030 baseline projection and a 2030 projection with nonroad controls.

The model outputs from the 1996, 2020 and 2030 baselines, combined with current air quality data, were used to identify areas expected to exceed the ozone NAAQS in 2020 and 2030. These areas became candidates for being determined to be residual exceedance areas which will require additional emission reductions to attain and maintain the ozone NAAQS. The impacts of the proposed controls were determined by comparing the model results in the future year control

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[N] Because of the complexities and non-linear relationships in the air quality modeling, we are not attempting to make any adjustments to the results. Instead, we are presenting the results for the preliminary control option with information about how the emissions changes relate to what was modeled.

runs against the baseline simulations of the same year. This modeling supports the conclusion that there is a broad set of areas with predicted ozone concentrations at or above 0.085 ppm between 1996 and 2030 in the baseline scenarios without additional emission reductions.

The air quality modeling performed for this rule was based upon the same modeling system as was used in the EPA's air quality assessment of the Clear Skies legislation with the addition of updated inventory estimates for 1996, 2020 and 2030. Further discussion of this modeling, including evaluations of model performance relative to predicted future air quality, is provided in the AQ Modeling TSD.

CAMx was utilized to estimate base and future-year ozone concentrations over the Eastern and Western U.S. for the various emissions scenarios. CAMx simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of ozone. CAMx is a photochemical grid model that numerically simulates the effects of emissions, advection, diffusion, chemistry, and surface removal processes on pollutant concentrations within a three-dimensional grid. This model is commonly used for purposes of determining attainment/non-attainment as well as estimating the ozone reductions expected to occur from a reduction in emitted pollutants. The following sections provide an overview of the ozone modeling completed as part of this rulemaking. More detailed information is included in the AQ Modeling TSD, which is located in the docket for this rule.

The regional ozone analyses used the modeling domains used previously for OTAG and the on-highway passenger vehicle Tier 2 rulemaking. The Eastern modeling domain encompasses the area from the East coast to mid-Texas and consists of two grids with differing resolutions. The model resolution was 36 km over the outer portions of the domain and 12 km in the inner portion of the grids. The vertical height of the eastern modeling domain is 4,000 meters above ground level with 9 vertical layers. The western modeling domain encompasses the area west of the 99th degree longitude (which runs through North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas) and also consists of two grids with differing resolutions. The vertical height of the western modeling domains is 4,800 meters above ground level with 11 vertical layers. As for the Eastern U.S., the model resolution was 36 km over the outer portions of the domain and 12 km in the inner portion of the grids.

The simulation periods modeled by CAMx included several multi-day periods when ambient measurements were representative of ozone episodes over the eastern and western U.S. A simulation period, or episode, consists of meteorological data characterized over a block of days that are used as inputs to the air quality model. Three multi-day meteorological scenarios during the summer of 1995 were used in the model simulations over the Eastern U.S.: June 12-24, July 5-15, and August 7-21. Two multi-day meteorogical scenarios during the summer of 1996 were used in the model simulations over the western U.S.: July 5-15 and July 18-31. In general, these episodes do not represent extreme ozone events but, instead, are generally representative of ozone levels near local design values. Each of the five emissions scenarios (1996 base year, 2020 base, 2020 control, 2030 baseline, 2030 control) were simulated for the selected episodes.

The meteorological data required for input into CAMx (wind, temperature, vertical mixing, etc.) were developed by separate meteorological models. For the eastern U.S., the gridded meteorological data for the three historical 1995 episodes were developed using the Regional Atmospheric Modeling System (RAMS), version 3b. This model provided needed data at every grid cell on an hourly basis. For the western U.S., the gridded meteorological data for the two historical 1996 episodes were developed using the Fifth-Generation National Center for Atmospheric Research (NCAR) / Penn State Mesoscale Model (MM5). These meteorological modeling results were evaluated against observed weather conditions before being input into CAMx and it was concluded that the model fields were adequate representations of the historical meteorology. A more detailed description of the settings and assorted input files employed in these applications is provided in the AQ Modeling TSD, which is located in the docket for this rule.

The modeling assumed background pollutant levels at the top and along the periphery of the domain as in Tier 2. Additionally, initial conditions were assumed to be relatively clean as well. Given the ramp-up days and the expansive domains, it is expected that these assumptions will not affect the modeling results, except in areas near the boundary (e.g., Dallas-Fort Worth TX). The other non-emission CAMx inputs (land use, photolysis rates, etc.) were developed using procedures employed in the on-highway light duty Tier 2/OTAG regional modeling. The development of model inputs is discussed in greater detail in the AQ Modeling TSD, which is available in the docket for this rule.

2.3.2.2.4 Model Performance Evaluation

The purpose of the base year photochemical ozone modeling was to reproduce the atmospheric processes resulting in the observed ozone concentrations over these domains and episodes. One of the fundamental assumptions in air quality modeling is that a model which adequately replicates observed pollutant concentrations in the base year can be used to assess the effects of future year emissions controls.

A series of performance statistics was calculated for both model domains, the four quadrants of the eastern domain, and multiple subregions in the eastern and western domains. Table 2.3-2 summarizes the performance statistics. The model performance evaluation consisted solely of comparisons against ambient surface ozone data. There was insufficient data available in terms of ozone precursors or ozone aloft to allow for a more complete assessment of model performance. Three primary statistical metrics were used to assess the overall accuracy of the base year modeling simulations.

- Mean normalized bias is defined as the average difference between the hourly model predictions and observations (paired in space and time) at each monitoring location, normalized by the magnitude of the observations.

- Mean normalized gross error is defined as the average absolute difference between the hourly model predictions and observations (paired in space and time) at each monitoring location, normalized by the magnitude of the observations.

- Average accuracy of the peak is defined as the average difference between peak daily model predictions and observations at each monitoring location, normalized by the magnitude of the observations.

In general, the model tends to underestimate observed ozone, especially in the modeling over the western U.S. as shown in Table 2.3-2. When all hourly observed ozone values greater than a 60 ppb threshold are compared to their model counterparts for the 30 episode modeling days in the eastern domain, the mean normalized bias is -1.1 percent and the mean normalized gross error is 20.5 percent. When the same statistics are calculated for the 19 episode days in the western domain, the bias is -21.4 percent and the error is 26.1 percent.

Table 2.3-2.
Model Performance Statistics for the CAMx Ozone Predictions: Base Case

Region	Episode	Average Accuracy of the Peak	Mean Normalized Bias	Mean Normalized Gross Error
Eastern U.S.	June 1995	-7.3	-8.8	19.6
	July 1995	-3.3	-5.0	19.1
	August 1995	9.6	8.6	623.3
Western U.S.	July 1996	-20.5	-21.4	26.1

At present, there are no guidance criteria by which one can determine if a regional ozone modeling exercise is exhibiting adequate model performance. These base case simulations were determined to be acceptable based on comparisons to previously completed model rulemaking analyses (e.g., Ozone Transport Assessment Group (OTAG), the light-duty passenger vehicle Tier-2 standards, and on highway Heavy-Duty Diesel Engine 2007 standards). The modeling completed for this proposal exhibits less bias and error than any past regional ozone modeling application done by EPA. Thus, the model is considered appropriate for use in projecting changes in future year ozone concentrations and the resultant health/economic benefits due to the proposed emissions reductions.

2.3.2.2.5 Results of Photochemical Ozone Modeling: Areas at Risk of Future 8-Hour Violations

This next section summarizes the results of our modeling of ozone air quality impact of reductions in nonroad diesel emissions. Specifically, it provides information on our calculations of the number of people estimated to live in counties in which ozone monitors are predicted to exceed design values or to be within 10 percent of the design value in the future. We also provide specific information about the number of people who would repeatedly experience levels of ozone of potential concern over prolonged periods, i.e., over 0.085 ppm ozone 8-hour concentrations over a number of days.

The determination that an area is at risk of exceeding the ozone standard in the future was made for all areas with current design values greater than or equal to 0.085 ppm (or within a 10 percent margin) and with modeling evidence that concentrations at and above this level will persist into the future. The following sections provide background on methods for analysis of attainment and maintenance. Those interested in greater detail should review the AQ TSD and AQ Modeling TSD, which are both available in the docket to this rule.

The relative reduction factor method was used for interpreting the future-year modeling results to determine where nonattainment is expected to occur in the 2020 and 2030 control cases. The CAMx simulations were completed for base cases in 1996, 2020, and 2030 considering growth and expected emissions controls that will affect future air quality. The effects of the nonroad engine reductions (control cases) were modeled for the two future years. As a means of assessing the future levels of air quality with regard to the ozone NAAQS, future-year estimates of ozone design values were calculated based on relative reduction factors (RRF) between the various baselines and 1999-2001 ozone design values. The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling for an 8-hour ozone standard.[272] Hourly model predictions were processed to determine daily maximum 8-hour concentrations for each grid cell for each non-ramp-up day modeled. The RRF for a monitoring site was determined by first calculating the multi-day mean of the 8-hour daily maximum predictions in the nine grid cells surrounding the site using only those predictions greater than or equal to 70 ppb, as recommended in the guidance.[O] [273] This calculation was performed for the base year scenario and each of the future-year baselines. The RRF for a site is the ratio of the mean prediction in the future-year scenario to the mean prediction in the base year scenario. RRFs were calculated on a site-by-site basis. The future-year design value projections were then calculated by county, based on the highest resultant design values for a site within that county from the RRF application.

Based upon our air quality modeling for this proposal, we anticipate that without emission reductions beyond those already required under promulgated regulation and approved SIPs, ozone nonattainment will likely persist into the future. With reductions from programs already in place (but excluding the proposed nonroad diesel reductions), the number of counties violating the ozone 8-hour standard is expected to decrease in 2020 to 30 counties where 43 million people are projected to live.[274] Thereafter, exposure to unhealthy levels of ozone is expected to begin to increase again. In 2030 the number of counties violating the ozone 8-hour NAAQS without the nonroad diesel emissions reductions proposed today is projected to increase to 32 counties where 47 million people are projected to live.

EPA is still developing the implementation process for bringing the nation's air into

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[O] For the one-hour NAAQS we used a cut-off of 80 ppb. Please see the On-highway Passenger Vehicle Tier 2 Air Quality Modeling TSD for more details (EPA 1999b).

attainment with the ozone 8-hour NAAQS. EPA's current plans call for designating ozone 8-hour nonattainment areas in April 2004. EPA is planning to propose that States submit SIPs that address how areas will attain the 8-hour ozone standard within three years after nonattainment designation regardless of their classification. EPA is also planning to propose that certain SIP components, such as those related to reasonably available control technology (RACT) and reasonable further progress (RFP) be submitted within 2 years after designation. We therefore anticipate that States will submit their attainment demonstration SIPs by April 2007. Section 172(a)(2) of the Clean Air Act requires that SIP revisions for areas that may be covered only under subpart 1 of part D, Title I of the Act demonstrate that the nonattainment areas will attain the ozone 8-hour standard as expeditiously as practicable but no later than five years from the date that the area was designated nonattainment. However, based on the severity of the air quality problem and the availability and feasibility of control measures, the Administrator may extend the attainment date "for a period of no greater than 10 years from the date of designation as nonattainment." Based on these provisions, we expect that most or all areas covered under subpart 1 will attain the ozone standard in the 2007 to 2014 time frame. For areas covered under subpart 2, the maximum attainment dates will range from 3 to 20 years after designation, depending on an area's classification. Thus, we anticipate that areas covered by subpart 2 will attain in the 2007 to 2014 time period.

Furthermore, the inventories that underlie the ozone modeling conducted for this rulemaking included reductions from all current or committed federal, State and local controls and, for the control case, the proposed nonroad diesel program itself. It did not did not attempt to examine the prospects of areas attaining or maintaining the ozone standard with possible future controls (i.e., controls beyond current or committed federal, State and local controls). Therefore, Tables 2.2-3 and 2.2-4 below should be interpreted as indicating what areas are at risk of ozone violations in 2020 or 2030 without additional federal or State measures that may be adopted and implemented after this rulemaking is finalized. We expect many of the areas listed in Table 2.2-3 to adopt additional emission reduction programs, but we are unable to quantify or rely upon future reductions from additional State programs since they have not yet been adopted.

Since the emission reductions expected from today's proposal would begin in the same time period in which areas will need reductions to attain by their attainment dates, the projected reductions in nonroad emissions would be extremely important to States in meeting the new NAAQS. It is our expectation that States will be relying on such nonroad reductions in order to help them attain and maintain the 8-hour NAAQS.   Furthermore, since the nonroad emission reductions will continue to grow in the years beyond 2014, they will also be important for maintenance of the NAAQS for areas with attainment dates of 2014 and earlier.

On a population weighted basis, the average change in future year design values would be a decrease of 1.8 ppb in 2020, and 2.5 ppb in 2030. Within nonattainment areas, the average decrease would be somewhat higher: 1.9 ppb in 2020 and 3 ppb in 2030.[P] In terms of modeling accuracy, the count of modeled non-attaining counties is much less certain than the average changes in air quality. For example, actions by states to meet their SIP obligations would not be expected to significantly change the overall concentration changes induced by this proposal, but they could substantially change the count of counties in or out of attainment. If state actions resulted in an increase in the number of areas that are very close to, but still above, the NAAQS, then this rule might bring many of those counties down sufficiently to change their attainment status. On the other hand, if state actions brought several counties we project to be very close to the standard in the future down sufficiently to reach attainment status, then the air quality improvements from today's proposal might change the actual attainment status of very few counties. Bearing this limitation in mind, our modeling indicates that the nonroad diesel emissions reductions would decrease the net number of nonattainment counties by 2 in 2020 and by 4 in 2030, without consideration of new state programs.

Areas presented in Table 2.3-3 and 2.3-4 have monitored 1999-2001 air quality data indicating violations of the 8-hour ozone NAAQS, or are within 10 percent of the standard, and are predicted to have exceedances in 2020 or 2030 without the reductions from this rule. Table 2.3-3 lists those counties with predicted exceedances of the 8-hour ozone standard in 2020 or 2030 without emission reductions from this rule (i.e., base cases). These areas are listed in columns with a "b" after the year (e.g., 2020b). Table 2.3-2 also lists those counties with predicted exceedances of the 8-hour ozone standard in 2020 and 2030, with emission reductions from this rule (i.e., control case). These areas are listed in columns with a "c" after the year (e.g., 2020c). An area was considered likely to have future exceedances if exceedances were predicted by the model, and the area is currently violating the 8-hour ozone standard, or is within 10 percent of violating the 8-hour ozone standard.

In Table 2.3-3 we list the counties with 2020 and 2030 projected 8-hour ozone design values (4th maximum concentration) that violate the 8-hour standard. Counties are marked with an "V" in the table if their projected design values are greater than or equal to 85 ppb. The current 3-year average design values of these counties are also listed. Recall that we project future design values only for counties that have current design values, so this list is limited to those counties with ambient monitoring data sufficient to calculate current design values.

[P] This is in spite of the fact that NOx reductions can at certain times in some areas cause ozone levels to increase. Such "disbenefits" are observed in our modeling, but these results make clear that the overall effect of the proposed rule is positive.

Table 2.3-3: Counties with 2020 and 2030 Projected Ozone Design Values in Violation of the 8-Hour Ozone Standard.[a]

State	County	1999 - 2001 Design Value (ppb)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
CA	Fresno	108	V	V	V	V	799,407
CA	Kern	109	V	V	V	V	661,645
CA	Los Angeles	105	V	V	V	V	9,519,338
CA	Orange	77	V	V	V	V	2,846,289
CA	Riverside	111	V	V	V	V	1,545,387
CA	San Bernardino	129	V	V	V	V	1,709,434
CA	Ventura	101	V	V	V	V	753,197
CT	Fairfield	97	V	V	V	V	882,567
CT	Middlesex	99	V	V	V	V	155,071
CT	New Haven	97	V	V	V	V	824,008
GA	Bibb	98	V		V		153,887
GA	Fulton	107	V	V	V		816,006
GA	Henry	107	V		V		119,341
IL	Cook	88	V	V	V	V	5,376,741
IN	Lake	90			V		484,564
MD	Harford	104	V		V		218,590
MI	Macomb	88			V	V	788,149
MI	Wayne	88	V	V	V	V	2,061,162
NJ	Camden	103	V	V	V	V	508,932
NJ	Gloucester	101	V	V	V	V	254,673
NJ	Hudson	93	V	V	V	V	608,975
NJ	Hunterdon	100	V	V	V	V	121,989
NJ	Mercer	105	V	V	V	V	350,761
NJ	Middlesex	103	V	V	V	V	750,162
NJ	Ocean	109	V	V	V	V	510,916
NY	Bronx	83		V		V	1,332,650
NY	Richmond	98	V	V	V	V	443,728
NY	Westchester	92	V	V	V	V	923,459
PA	Bucks	105	V	V	V	V	597,635
PA	Montgomery	100	V	V	V	V	750,097
TX	Galveston	98	V	V	V	V	250,158
TX	Harris	110	V	V	V	V	3,400,578
WI	Kenosha	95	V	V	V	V	149,577
Number of Violating Counties			30	28	32	28	
Population of Violating Counties[b]			42,930,060	43,532,490	46,998,413	46,038,489	

[a] The proposed emission reductions differs based on updated information (see Chapter 3.6); however, the base results presented here would not change, but we anticipate the control case improvements would generally be smaller.

[b] Populations are based on 2020 and 2030 estimates from the U.S. Census.

In Table 2.3-4 we present the counties with 2020 and 2030 projected 8-hour ozone design values that do not violate the annual standard, but are within 10 percent of it. Counties are marked with an “X” in the table if their projected design values are greater than or equal to 77 ppb, but less 85 ppb. Counties are marked with a “V” in the table if their projected design values are greater than or equal to 85 ppb. The current 3-year average design values of these counties are also listed. These are counties that are not projected to violate the standard, but to be close to it, so the proposed rule will help assure that these counties continue to meet the standard.

Table 2.3-4
Counties with 2020 and 2030 Projected Ozone Design Values
within Ten Percent of the 8-Hour Ozone Standard.[a]

State	County	1999 - 2001 Design Value (ppb)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
AR	Crittenden	92	X	X	X	X	50,866
AZ	Maricopa	85	X	X	X	X	3,072,149
CA	Kings	98	X	X	X	X	129,461
CA	Merced	101	X	X	X	X	210,554
CA	Tulare	104	X	X	X	X	368,021
CO	Jefferson	81	X	X	X	X	527,056
CT	New London	90	X		X		259,088
DC	Washington	94	X	X	X	X	572,059
DE	New Castle	97	X	X	X	X	500,265
GA	Bibb	98	V	X	V	X	153,887
GA	Coweta	96	X	X	X	X	89,215
GA	De Kalb	102	X	X	X	X	665,865
GA	Douglas	98	X		X		92,174
GA	Fayette	99	X		X		91,263
GA	Fulton	107	V	V	V	X	816,006
GA	Henry	107	V	X	V	X	119,341
GA	Rockdale	104	X	X	X	X	70,111
IL	McHenry	83	X		X		260,077
IN	Lake	90	X	X	V	X	484,564
IN	Porter	90	X	X	X	X	146,798
LA	Ascension	86	X	X	X	X	76,627
LA	Bossier	90	X	X	X	X	98,310
LA	Calcasieu	86	X	X	X	X	183,577
LA	East Baton Rou	91	X	X	X	X	412,852
LA	Iberville	86	X		X		33,320
LA	Jefferson	89	X	X	X	X	455,466
LA	Livingston	88	X	X	X	X	91,814
LA	St Charles	86	X	X	X	X	48,072
LA	St James	83			X		21,216

State	County	1999 - 2001 Design Value (ppb)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
LA	St John The Ba	86	X	X	X	X	43,044
LA	West Baton Rou	88	X	X	X	X	21,601
MA	Barnstable	96	X		X		222,230
MA	Bristol	93	X		X		534,678
MD	Anne Arundel	103	X	X	X	X	489,656
MD	Baltimore	93	X	X	X	X	754,292
MD	Cecil	106	X	X	X	X	85,951
MD	Harford	104	V	X	V	X	218,590
MD	Kent	100	X		X		19,197
MD	Prince Georges	97	X	X	X		801,515
MI	Benzie	89	X		X		15,998
MI	Macomb	88	X	X	V	V	788,149
MI	Mason	91	X		X		28,274
MI	Muskegon	92	X	X	X		170,200
MI	Oakland	84	X	X	X	X	1,194,156
MI	St Clair	85			X		164,235
MO	St Charles	90			X		283,883
MO	St Louis	88			X		1,016,315
MS	Hancock	87	X		X		42,967
MS	Harrison	89	X	X	X	X	189,601
MS	Jackson	87	X	X	X	X	131,420
NJ	Cumberland	97	X		X		146,438
NJ	Monmouth	94	X	X	X	X	615,301
NJ	Morris	97	X	X	X	X	470,212
NJ	Passaic	89	X	X	X	X	489,049
NY	Bronx	83	X	V	X	V	1,332,650
NY	Erie	92	X	X	X	X	950,265
NY	Niagara	87	X		X		219,846
NY	Putnam	89	X		X		95,745
NY	Suffolk	91	X	X	X	X	1,419,369
OH	Geauga	93	X		X		90,895
OH	Lake	91	X		X		227,511
PA	Allegheny	92	X		X		1,281,666
PA	Delaware	94	X	X	X	X	550,864
PA	Lancaster	96	X		X		470,658
PA	Lehigh	96	X	X	X	X	312,090
PA	Northampton	97	X	X	X	X	267,066
PA	Philadelphia	88	X	X	X	X	1,517,550
RI	Kent	94	X	X	X		167,090

State	County	1999 - 2001 Design Value (ppb)	2020		2030		Population in 2000
			Base	Control[a]	Base	Control[a]	
RI	Washington	92	X		X		123,546
TN	Shelby	93	X	X	X	X	897,472
TX	Brazoria	91	X	X	X	X	241,767
TX	Collin	99	X	X	X	X	491,675
TX	Dallas	93	X	X	X	X	2,218,899
TX	Denton	101	X	X	X	X	432,976
TX	Jefferson	85	X	X	X	X	252,051
TX	Montgomery	91	X		X	X	293,768
TX	Tarrant	97	X	X	X	X	1,446,219
VA	Alexandria City	88			X		128,283
VA	Arlington	92	X	X	X	X	189,453
VA	Fairfax	95	X	X	X	X	969,749
WI	Door	93	X	X	X	X	27,961
WI	Kewaunee	89	X		X		20,187
WI	Manitowoc	92	X	X	X		82,887
WI	Milwaukee	89	X	X	X	X	940,164
WI	Ozaukee	95	X	X	X	X	82,317
WI	Racine	87	X		X		188,831
WI	Sheboygan	95	X	X	X	X	112,646
WI	Waukesha	86	X		X		360,767
Number of Counties within 10%			79	58	82	54	
Population of Counties within 10%[b]			40,465,492	33,888,031	44,013,587	35,631,215	

[a] The proposed emission reductions differs based on updated information (see Chapter 3.6); however, the base results presented here would not change, but we anticipate the control case improvements would generally be smaller.
[b] Populations are based on 2020 and 2030 estimates from the U.S. Census.

Based on our modeling, we are also able to provide a quantitative prediction of the number of people anticipated to reside in counties in which ozone concentrations are predicted to for 8-hour periods in the range of 0.085 to 0.12 ppm and higher on multiple days. Our analysis relies on projected county-level population from the U.S. Department of Census for the period representing each year analyzed.

For each of the counties analyzed, we determined the number of days for periods on which the highest model-adjusted 8-hour concentration at any monitor in the county was predicted, for example, to be equal to or above 0.085 ppm. We then grouped the counties which had days with ozone in this range according to the number of days this was predicted to happen, and summed their projected populations.

In the base case (i.e., before the application of emission reductions resulting from this rule), we estimated that in 2020 53 million people are predicted to live in counties with at least 2 days with 8-hour average concentrations of 0.085 ppm or higher. This baseline will increase in 2030 to 56 million people are predicted to live in counties with at least 2 days with 8-hour average concentrations of 0.085 ppm or higher. About 30 million people live in counties with at least 7 days of 8-hour ozone concentrations at or above 0.085 ppm in 2020 and 2030 without additional controls. Approximately 15 million people are predicted to live in counties with at least 20 days of 8-hour ozone concentrations at or above 0.085 ppm in 2020 and 2030 without additional controls. Thus, reductions in ozone precursors from nonroad diesel engines are needed to assist States in meeting the ozone NAAQS and to reduce ozone exposures.

2.3.2.3 Potentially Counterproductive Impacts on Ozone Concentrations from NOx Emissions Reductions

While the proposed rule would reduce ozone levels generally and provide significant ozone-related health benefits, this is not always the case at the local level. Due to the complex photochemistry of ozone production, NOx emissions lead to both the formation and destruction of ozone, depending on the relative quantities of NOx, VOC, and ozone catalysts such as the OH and HO_2 radicals. In areas dominated by fresh emissions of NOx, ozone catalysts are removed via the production of nitric acid which slows the ozone formation rate. Because NOx is generally depleted more rapidly than VOC, this effect is usually short-lived and the emitted NOx can lead to ozone formation later and further downwind. The terms “NOx disbenefits” or “ozone disbenefits” refer to the ozone increases that can result from NOx emissions reductions in these localized areas. According to the NARSTO Ozone Assessment, these disbenefits are generally limited to small regions within specific urban cores and are surrounded by larger regions in which NOx control is beneficial.[275]

In the context of ozone disbenefits, some have postulated that present-day weekend conditions serve as a demonstration of the effects of future NOx reduction strategies because NOx emissions decrease more than VOC emissions on weekends, due to a disproportionate decrease in the activity of heavy-duty diesel trucks and other diesel equipment. Recent research indicates that ambient ozone levels are higher in some metropolitan areas on weekends than weekdays.[276, 277] There are other hypotheses for the cause of the “weekend effect.”[278] For instance, the role of ozone and ozone precursor carryover from previous days is difficult to evaluate because of limited ambient data, especially aloft. The role of the changed timing of emissions is difficult to evaluate because of limited ambient and emissions inventory information. It is also important to note that in many areas with “weekend effects” (e.g., Los Angeles and San Francisco) significant ozone reductions have been observed over the past 20 years for all days of the week, during a period in which both NOx and VOC emissions have been greatly reduced.

EPA maintains that the best available approach for determining the value of a particular emissions reduction strategy is the net air quality change projected to result from the rule, evaluated on a nationwide basis and for all pollutants that are health and/or welfare concerns. The primary tool for assessing the net impacts of this rule are the air quality simulation models[279]. Model scenarios of 2020 and 2030 with and without the proposed controls are compared to determine the expected changes in future pollutant levels resulting from the proposed rule. There are several factors related to the air quality modeling and inputs which should be considered regarding the disbenefit issue. First, our future year modeling conducted does not contain any local governmental actions beyond the controls proposed in this rule. It is possible that significant local controls of VOC and/or NOx could modify the conclusions regarding ozone changes in some areas. Second, the modeled NOx reductions are greater than those actually included in the proposal (see Section 3.6 for more detail). This could lead to an exaggeration of the benefits and disbenefits expected to result from the rule. Also, recent work by CARB has indicated that model limitations and uncertainties may lead to overestimates of ozone disbenefits attributed to NOx emission reductions. While EPA maintains that the air quality simulations conducted for the rule represent state-of-the-science analyses, any changes to the underlying chemical mechanisms, grid resolution, and emissions/meteorological inputs could result in revised conclusions regarding the strength and frequency of ozone disbenefits.

A wide variety of ozone metrics were considered in the assessment of the proposed emissions reductions. Three of the most important assessments are: 1) the effect of the proposed rule on projected future-year ozone violations, 2) the effect of the proposed rule in assisting local areas in attainment and maintenance of the NAAQS, and 3) an economic assessment of the rule benefits based on existing health studies. Additional metrics for assessing the air quality effects are discussed in the TSD for the modeling.

Based only on the reductions from today's rule, our modeling predicts that periodic ozone disbenefits will occur most frequently in New York City, Los Angeles, and Chicago. Smaller and less frequent disbenefits also occur in Boston, Detroit, and San Francisco. As described below, despite these localized increases, the net ozone impact of the rule nationally is positive for the majority of the analysis metrics. Even within the few metropolitan areas that experience periodic ozone increases, these disbenefits are infrequent relative to the benefits accrued at ozone levels above the NAAQS. Furthermore, and most importantly, the overall air quality impact of the proposed controls is projected to be strongly positive due to the expected reductions in fine PM.

The net impact of the proposed rule on projected 8-hour ozone violations in 2020 is that three counties would no longer violate the NAAQS[280]. Conversely, one county in the NewYork City CMSA (Bronx County) which is currently not in violation of the NAAQS is projected to violate the standard in 2020 as a result of the rule. The net effect is a projected 1.4 percent increase in the population living in violating counties. It is important to note that ozone nonattainment designations are historically based on larger geographical areas than counties. Bronx County, NY is the only county within the New York City CMSA in which increases are detected in 8-hour violations in 2020. Considering a larger area, the modeling indicates that projected violations over the entire New York City CMSA will be reduced by 6.8 percent. Upon full turnover of the fleet in 2030, the net impact of the rule on projected 8-hour ozone violations is a 2.0 percent decrease in the population living in violating counties as two additional counties are no longer projected to violate the NAAQS. The net impact of the rule on projected 1-hour ozone violations is to eradicate projected violations from four counties (in both 2020 and 2030), resulting in a 10.5 percent decrease in the population living in violating counties.

Another way to assess the air quality impact of the rule is to calculate its effect on all projected future year design values concentrations, as opposed to just those that cross the threshold of the NAAQS. This metric helps assess the degree to which the rule will assist local areas in attaining and/or maintaining the NAAQS. Future year design values were calculated for every location for which complete ambient monitoring data existed for the period 1999-2001. These present-day design values were then projected by using the modeling projections (future base vs. future control) in a relative sense. For the 1999-2001 monitoring period, there were sites in 522 counties for which 8-hour design values could be calculated and sites in 510 counties for which 1-hour design values could be calculated.

Table 2.3.2-1 shows the average change in future year eight-hour and one-hour ozone design values. Average changes are shown 1) for all counties with design values in 2001, 2) for counties with design values that did not meet the standard in 1999-2001 (“violating” counties), and 3) for counties that met the standard, but were within 10 percent of it in 1999-2001. This last category is intended to reflect counties that meet the standard, but will likely benefit from help in maintaining that status in the face of growth. The average and population-weighted average over all counties in Table 2.3.2-1 demonstrates a broad improvement in ozone air quality. The average across violating counties shows that the rule will help bring these counties into attainment. The average over counties within ten percent of the standard shows that the rule will also help those counties to maintain the standard. All of these metrics show a decrease in 2020 and a larger decrease in 2030 (due to fleet turnover), indicating in four different ways the overall improvement in ozone air quality as measured by attainment of the NAAQS.

Table 2.3.2-1
Average Change in Projected Future-Year Ozone Design Value[f]

Design Value	Average[a]	Number of Counties	2020 Control[f] minus Base (ppb)	2030 Control[f] minus Base (ppb)
8-Hour	All	522	-1.8	-2.8
	All, population-weighted	522	-1.6	-2.6
	Violating counties[b]	289	-1.9	-3
	Counties within 10 percent of the standard[c]	130	-1.7	-2.6
1-Hour	All	510	-2.4	-3.8
	All, population-weighted	510	-2.3	-3.6
	Violating counties[d]	73	-2.9	-4.5
	Counties within 10 percent of the standard[e]	130	-2.4	-3.8

[a] Averages are over counties with 2001 design values.

[b] Counties whose present-day design values exceeded the 8-hour standard (≥ 85 ppb).

[c] Counties whose present-day design values were less than but within 10 percent of the 8-hour standard (77≤DV<85 ppb).

[d] Counties whose present-day design values exceeded the 1-hour standard (≥ 125 ppb).

[e] Counties whose present-day design values were less than but within 10 percent of the 1-hour standard (112≤DV<125 ppb) in 2001.

[f] The proposal differs based on updated information; however, we believe that the net results would approximate future emissions, although we anticipate the design value improvements would generally be slightly smaller.

Table 2.3.2-2 presents counts of the same set of counties (those with 1999-2001 design values) examined by the size and direction of their change in design value in 2020 and 2030. For the 8-hour design value, 96 percent of counties show a decrease in 2020, 97 percent in 2030. For the 1-hour design value, 97 percent of counties show a decrease in 2020, 98 percent in 2030.

Table 2.3.2-2
Numbers of Counties Projected to Be in
Different Design-Value Change Bins in 2020 and 2030 as a Result of the Rule[a]

Design value change	2020		2030	
	8-Hour	1-Hour	8-Hour	1-Hour
≥ 2ppb increase	1	1	1	1
1 ppb increase	1	5	3	2
No change	21	10	10	5
1 ppb decrease	140	69	42	22
2-3 ppb decrease	357	356	333	193
4 ppb decrease	2	69	133	287
Total	522	510	522	510

[a] The proposal differs based on updated information; however, we believe that the net results would approximate future emissions, although we anticipate the design value improvements would generally be slightly smaller.

A third way to assess the impacts of the rule is an economic consideration of the economic benefits. Benefits related to changes in ambient ozone are expected to be positive for the nation as a whole. However, for certain health endpoints which are associated with longer ozone averaging times, such as minor restricted activity days related to 24 hour average ozone, the national impact may be small or even negative. This is due to the forecasted increases in ozone for certain hours of the day in some urban areas. Many of the increases occur during hours when baseline ozone levels are low, but the benefits estimates rely on the changes in ozone along the full distribution of baseline ozone levels, rather than changes occurring only above a particular threshold. As such, the benefits estimates are more sensitive to increases in ozone occurring due to the "NOx disbenefits" effect described above. For more details on the economic effects of the rule, please see Chapter 9: Public Health and Welfare Benefits.

Historically, NOx reductions have been very successful at reducing regional/national ozone levels[1]. Consistent with that fact, the photochemical modeling completed for this rule indicates that the emissions reductions proposed today will significantly assist in the attainment and maintenance of the ozone NAAQS at the national level. Furthermore, NOx reductions also result in reductions in PM and its associated health and welfare effects. This rule is one aspect of overall emissions reductions that States, local governments, and Tribes need to reach their clean air goals. It is expected that future local and national controls that decrease VOC, CO, and regional ozone will mitigate any localized disbenefits. EPA will continue to rely on local attainment measures to ensure that the NAAQS are not violated in the future. Many organizations with an interest in improved air quality support the rule because they believe the resulting NOx reductions would reduce both ozone and PM[281]. EPA believes that a balanced air quality management approach that includes NOx emissions reductions from nonroad engines is needed as part of the Nation's progress toward clean air.

Another category of potential effects that may change in response to ozone reduction strategies results from the shielding provided by ozone against the harmful effects of ultraviolet radiation (UV-B) derived from the sun. The great majority of this shielding results from naturally occurring ozone in the stratosphere, but the 10 percent of total "column"ozone present in the troposphere also contributes.[282] A variable portion of this tropospheric fraction of UV-B shielding is derived from ground level ozone related to anthropogenic air pollution. Therefore, strategies that reduce ground level ozone could, in some small measure, increase exposure to UV-B from the sun.

While it is possible to provide quantitative estimates of benefits associated with globally based strategies to restore the far larger and more spatially uniform stratospheric ozone layer, the changes in UV-B exposures associated with ground level ozone reduction strategies are much more complicated and uncertain. Comparatively smaller changes in ground-level ozone (compared to the total ozone in the troposphere) and UV-B are not likely to measurably change long-term risks of adverse effects.

2.3.3 Welfare Effects Associated with Ozone and its Precursors

There are a number of significant welfare effects associated with the presence of ozone and NO_X in the ambient air.[283] Because the proposed rule would reduce ground-level ozone and nitrogen deposition, benefits are expected to accrue to the welfare effects categories described in the paragraphs (subsections) below.

2.3.3.1 Ozone-related welfare effects.

The Ozone Criteria Document notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant."[284] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake". To a lesser extent, ozone can also diffuse directly through surface layers to the plant's interior.[285] Once ozone, a highly reactive substance, reaches the interior of plant cells, it inhibits or damages essential cellular components and functions, including enzyme activities, lipids, and cellular membranes, disrupting the plant's osmotic (i.e., water) balance and energy utilization patterns.[286] [287] This damage is commonly manifested as visible foliar injury such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or as reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[288] With fewer resources available, the plant reallocates existing resources away from root growth and storage, above ground growth or yield, and reproductive processes, toward leaf repair and maintenance. Studies have shown that plants stressed in these ways may exhibit a general loss of vigor which can lead to secondary impacts that modify plants' responses to other environmental factors. Specifically, plants may become more sensitive to other air pollutants, more susceptible to disease, insect attack, harsh weather (e.g., drought/frost) and other environmental stresses (e.g., increasing CO_2 concentrations). Furthermore, there is considerable evidence that ozone can interfere with the formation of mycorrhiza, essential symbiotic fungi associated with the roots of most terrestrial plants, by reducing the amount of carbon available for transfer from the host to the symbiont.[289]

Not all plants, however, are equally sensitive to ozone. Much of the variation in sensitivity between individual plants or whole species is related to the plant's ability to regulate the extent of gas exchange via leaf stomata (e.g., avoidance of O_3 uptake through closure of stomata).[290] [291] [292] Other resistance mechanisms may involve the intercellular production of detoxifying substances. Several biochemical substances capable of detoxifying ozone have been reported to occur in plants including the antioxidants ascorbate and glutathione. After injuries have occurred, plants may be capable of repairing the damage to a limited extent.[293] Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is toxic for all plants. However, in general, the science suggests that ozone concentrations of 0.10 ppm or greater can be phytotoxic to a large number of plant species, and can produce acute foliar injury responses, crop yield loss and reduced biomass production. Ozone concentrations below 0.10 ppm (0.05 to 0.09 ppm) can produce these effects in more sensitive plant species, and have the potential over a longer duration of creating chronic stress on vegetation that can lead to effects of concern associated with reduced carbohydrate production and decreased plant vigor.

The economic value of some welfare losses due to ozone can be calculated, such as crop yield loss from both reduced seed production (e.g., soybean) and visible injury to some leaf crops (e.g., lettuce, spinach, tobacco) and visible injury to ornamental plants (i.e., grass, flowers, shrubs), while other types of welfare loss may not be fully quantifiable in economic terms (e.g., reduced aesthetic value of trees growing in Class I areas).

Forests and Ecosystems. Ozone also has been shown conclusively to cause discernible injury to forest trees.[294] [295] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts.[296] Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[297] [298] [299]

Because plants are at the center of the food web in many ecosystems, changes to the plant community can affect associated organisms and ecosystems (including the suitability of habitats that support threatened or endangered species and below ground organisms living in the root zone). Ozone damages at the community and ecosystem-level vary widely depending upon numerous factors, including concentration and temporal variation of tropospheric ozone, species composition, soil properties and climatic factors.[300] In most instances, responses to chronic or recurrent exposure are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[301] [302] [303] It is not yet possible to predict ecosystem responses to ozone with much certainty; however, considerable knowledge of potential ecosystem responses has been acquired through long-term observations in highly damaged forests in the United States.

Given the scientific information establishing that ambient ozone levels cause visible injury to foliage of some sensitive forest species,[304] welfare benefits are also expected to accrue as a result of reductions in ambient ozone concentrations in the U.S. is the economic value the public receives from reduced aesthetic injury to forests.[305] However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Agriculture. Laboratory and field experiments have shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that “several economically important crop species are sensitive to ozone levels typical of those found in the U.S.”[306] In addition, economic studies have shown a relationship between observed ozone levels and crop yields.[307] [308] [309]

Urban Ornamentals. Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[310] This is therefore a potentially important welfare effects category. However, information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

2.3.3.2 Nitrogen (NO_X)-related welfare effects.

Agriculture. The proposed rule, by reducing NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers’ and commercial tree growers use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure.

In these areas, reductions in atmospheric deposition of nitrogen represent additional agricultural benefits.

Forests and Ecosystems. Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor.[311]

On the other hand, there is evidence that forest ecosystems in some areas of the United States are already or are becoming nitrogen saturated.[312] Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum, leading to reductions in tree growth or forest decline. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems, harming fish and other aquatic life.[313]

The reductions in ground-level ozone and nitrogen deposition that would result from the proposed rule would be expected to reduce the adverse impacts described above. In particular, it is expected that economic impacts, such as those related to reduced crop yields and forest productivity, would be reduced.

2.4 Carbon Monoxide

The standards being proposed today would also help reduce levels of other pollutants for which NAAQS have been established: carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Currently every area in the United States has been designated to be in attainment with the NO_2 NAAQS. As of November 4, 2002, there were 24 areas designated as non-attainment with the SO2 standard, and 14 designated CO non-attainment areas. The rest of this section describes issues related to CO.

2.4.1 General Background

Unlike many gases, CO is odorless, colorless, tasteless, and nonirritating. Carbon monoxide results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. These conditions are common during vehicle starting when air supply is restricted (“choked”), when vehicles are not tuned properly, and at high altitude, where “thin” air effectively reduces the amount of oxygen available for combustion (except in engines that are designed or adjusted to compensate for altitude). High concentrations of CO generally occur in areas with elevated mobile-source emissions. Carbon monoxide emissions increase dramatically in cold weather. This is because engines need more fuel to start at cold temperatures and because some emission control devices (such as oxygen sensors and catalytic converters) operate less efficiently when they are cold. Also, nighttime inversion conditions are more frequent in the colder months of the year. This is due to the enhanced stability in the atmospheric boundary layer, which inhibits vertical mixing of emissions from the surface.

As described in Chapter 3, nonroad diesel engines currently account for about one percent of the national mobile source CO inventory. EPA previously determined that the category of nonroad diesel engines cause or contribute to ambient CO and ozone in more than one non-attainment area (65 FR 76790, December 7, 2000). In that action EPA found that engines subject to this proposed rule contribute to CO non-attainment in areas such as Los Angeles, Phoenix, Spokane, Anchorage, and Las Vegas. Nonroad land-based diesel engines emitted 927,500 tons of CO in 1996 (1 percent of mobile source CO). Thus, nonroad diesel engines contribute to CO non-attainment in more than one of these areas.

Although nonroad diesel engines have relatively low per-engine CO emissions, they can be a significant source of ambient CO levels in CO non-attainment areas. Thus, the emissions benefits from this proposed rule will help areas to attain and maintain the CO NAAQS.

2.4.2 Health Effects of CO

Carbon monoxide enters the bloodstream through the lungs and forms carboxyhemoglobin (COHb), a compound that inhibits the blood’s capacity to carry oxygen to organs and tissues.[314, 315] Carbon monoxide has long been known to have substantial adverse effects on human health, including toxic effects on blood and tissues, and effects on organ functions. Although there are effective compensatory increases in blood flow to the brain, at some concentrations of COHb, somewhere above 20 percent, these compensations fail to maintain sufficient oxygen delivery, and metabolism declines.[316] The subsequent hypoxia in brain tissue then produces behavioral effects, including decrements in continuous performance and reaction time.[317]

Carbon monoxide has been linked to increased risk for people with heart disease, reduced visual perception, cognitive functions and aerobic capacity, and possible fetal effects.[318] Persons with heart disease are especially sensitive to carbon monoxide poisoning and may experience chest pain if they breathe the gas while exercising.[319] Infants, elderly persons, and individuals with respiratory diseases are also particularly sensitive. Carbon monoxide can affect healthy individuals, impairing exercise capacity, visual perception, manual dexterity, learning functions, and ability to perform complex tasks.[320]

Several recent epidemiological studies have shown a link between CO and premature morbidity (including angina, congestive heart failure, and other cardiovascular diseases. Several studies in the U.S. and Canada have also reported an association of ambient CO exposures with frequency of cardiovascular hospital admissions, especially for congestive heart failure (CHF). An association of ambient CO exposure with mortality has also been reported in epidemiological studies, though not as consistently or specifically as with CHF admissions. EPA reviewed these studies as part of the Criteria Document review process.[321]

2.4.3 CO Nonattainment

The current primary NAAQS for CO are 35 parts per million for the one-hour average and 9 parts per million for the eight-hour average. These values are not to be exceeded more than once per year. Air quality carbon monoxide value is estimated using EPA guidance for calculating design values. Over 22 million people currently live in the 13 non-attainment areas for the CO NAAQS.

Nationally, significant progress has been made over the last decade to reduce CO emissions and ambient CO concentrations. Total CO emissions from all sources have decreased 16 percent from 1989 to 1998, and ambient CO concentrations decreased by 39 percent. During that time, while the mobile source CO contribution of the inventory remained steady at about 77 percent, the highway portion decreased from 62 percent of total CO emissions to 56 percent while the nonroad portion increased from 17 percent to 22 percent.[322] Over the next decade, we would expect there to be a minor decreasing trend from the highway segment due primarily to the more stringent standards for certain light-duty trucks.[323] CO standards for passenger cars and other light-duty trucks and heavy-duty vehicles did not change as a result of other recent rulemakings.

As explained in Chapter 9, EPA currently does not have appropriate tools for modeling changes in ambient concentrations of CO or air toxics for input into a national benefits analysis. As noted above, CO has been linked to numerous health effects; however, we are unable to quantify the CO-related health or welfare benefits of the Nonroad Diesel Engine rule at this time. However, nonroad diesel engines do contribute to nonattainment in some areas. Thus, the emissions benefits from this proposed rule would help areas to attain and maintain the CO NAAQS.

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323. The more stringent standards refer to light light-duty trucks greater than 3750 pounds loaded vehicle weight, up through 6000 pounds gross vehicle weight rating (also known as LDT2).

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CHAPTER 3: Emissions Inventory

This chapter presents our analysis of the emission impact of the proposed rule for the four categories of nonroad diesel engines affected: land-based diesel engines, commercial marine diesel vessels, locomotives, and recreational marine diesel engines. New engine controls are being proposed for the land-based diesel engine category. For the other three nonroad diesel categories, no new engine controls are being proposed; however, the diesel fuel sulfur requirements are expected to decrease particulate matter less than 2.5 microns ($PM_{2.5}$) and sulfur dioxide (SO_2) emissions for these categories.

Section 3.1 presents an overview of the methodology used to generate the baseline inventories. The baseline inventories represent current and future emissions with only the existing standards. Sections 3.2 and 3.3 then describe the contribution of nonroad diesel engines to national and selected local baseline inventories, respectively. Section 3.4 describes the development of the controlled inventories, specifically the changes made to the baseline inputs to incorporate the proposed standards and fuel sulfur requirements. Section 3.5 follows with the expected emission reductions associated with the proposed rule. Section 3.6 concludes the chapter by describing the changes in the inputs and resulting emissions inventories between the preliminary baseline and control scenarios used for the air quality modeling and the updated baseline and control scenarios in this proposal.

The estimates of baseline emissions and emission reductions from the proposed rule for nonroad land-based, recreational marine, locomotive, and commercial marine vessel diesel engines are reported for both 48-state and 50-state inventories. The 48-state inventories are used for the air quality modeling that EPA uses to analyze regional ozone and PM air quality, of which Alaska and Hawaii are not a part. In addition, 50-state emission estimates for other sources (such as stationary and area sources) are not available. As a result, in cases where nonroad diesel sources are compared with other emission sources, the 48-state emission inventory estimates are used.

Inventories are presented for the following pollutants: $PM_{2.5}$, PM_{10}, oxides of nitrogen (NO_x), SO_2, volatile organic compounds (VOC), carbon monoxide (CO), and air toxics. The specific air toxics are benzene, formaldeyde, acetaldehyde, 1,3-butadiene, and acrolein. The PM inventories include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling.

3.1 Nonroad Diesel Baseline Emissions Inventory Development

This section describes how the baseline emissions inventories were developed for the four categories of nonroad diesel engines affected by this proposal: land-based diesel engines, commercial marine diesel vessels, locomotives, and recreational marine diesel engines. For land-based diesel engines, there is a section that discusses inventory development for $PM_{2.5}$, NO_x, SO_2, VOC, and CO, followed by a section for air toxics.

3.1.1 Land-Based Nonroad Diesel Engines—$PM_{2.5}$, NO_x, SO_2, VOC, and CO Emissions

The baseline emissions inventories for land-based diesel engines were generated using the draft NONROAD2002 model. The baseline inventories account for the effect of existing federal emission standards that establish three tiers of emission standards (Tier 1 through Tier 3). Section 3.1.1.1 provides an overview of the draft NONROAD2002 model and a description of the methodology used in the model to estimate emissions. Details of the baseline modeling inputs (e.g., populations, activity, and emission factors) for land-based diesel engines can be found in the technical reports documenting the draft NONROAD2002 model. The single scenario option variable that affects diesel emissions is the in-use fuel sulfur level. The in-use diesel fuel sulfur level inputs used for the baseline scenarios are given in Section 3.1.1.2.3.

3.1.1.1 Overview

The draft NONROAD2002 model estimates emissions inventories of important air emissions from diverse nonroad equipment. The model's scope includes all nonroad sources with the exception of locomotives, aircraft and commercial marine vessels. Users can construct inventories for criteria pollutants including carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_2), and particulate matter (PM), as well as other emissions including total hydrocarbon (THC) and carbon dioxide (CO_2). As a related feature, the model estimates fuel consumption. The model can distinguish emissions on the basis of equipment type, size and technology group. A central feature of the model is projection of future or past emissions between the years 1970 and 2050.

The draft NONROAD2002 model contains three major components: (1) the core model, a FORTRAN program that performs model calculations, (2) the reporting utility, a Microsoft Access application that compiles and presents results, and (3) the graphic user interface (GUI), a Visual-Basic application that allows users to easily construct scenarios for submission to the core model. The following discussion will describe processes performed by the core model in the calculation of emissions inventories.

This section describes how the draft NONROAD2002 model estimates emissions particularly relevant to this analysis, including particulate matter (PM), oxides of nitrogen (NO_x), oxides of sulfur (SO_2), carbon monoxide (CO) and volatile organic compounds (VOC). As appropriate, we will focus on estimation of emissions of these pollutants by diesel engines. The model estimates emissions from approximately 80 types of diesel equipment. As with other engine classes, the model defines engine or equipment "size" in terms of the rated power (horsepower) of the engine. For diesel engines, the proposed regulations also classify engines on the basis of rated power.

The first four chemical species are exhaust emissions, i.e., pollutants emitted directly as exhaust from combustion of diesel fuel in the engine. However, the last emission, VOC, includes both exhaust and evaporative components. The exhaust component represents hydrocarbons emitted as products of combustion; the evaporative component includes compounds emitted from unburned fuel during operation, i.e., “crankcase emissions.” For VOC, we will first describe estimation of total hydrocarbon exhaust emissions, in conjunction with the description for the other exhaust emissions. We discuss subsequent estimation of associated VOC emissions in subsection 3.1.1.4.

3.1.1.2 NONROAD’s Major Inputs

The draft NONROAD2002 model uses three major sets of inputs in estimation of exhaust emission inventories: (1) emissions calculation variables, (2) projection variables, and (3) scenario option variables.

3.1.1.2.1 Emissions Calculation Variables

The draft NONROAD2002 model estimates exhaust emissions using the equation

$$I_{exh} = E_{exh} \cdot A \cdot L \cdot P \cdot N$$

where each term is defined as follows:

I_{exh} = the exhaust emission inventory (gram/year, gram/day),
E_{exh} = exhaust emission factor (gram/hp-hr),
A = equipment activity (operating hours/year),
L = Load factor (average proportion of rated power used during operation (%)),
P = average rated power (hp)
N = Equipment population (units).

Emissions are then converted and reported as tons/year or tons/day.

For diesel engines, each of the inputs applies to sub-populations of equipment, as classified by type (dozer, tractor, backhoe, etc.), rated power class (50-100 hp, 100-300 hp, etc.) and regulatory tier (tier 1, tier 2, etc.).

Exhaust Emission Factor. The emission factor in a given simulation year consists of three components, a “zero-hour” emission level (ZHL) , a transient adjustment factor (TAF) and a deterioration factor (DF). The ZHL represents the emission rate for recently manufactured engines, i.e., engines with few operating hours, and is typically derived directly from laboratory measurements on new or nearly new engines on several commonly used duty cycles, hence the term “zero-hour.”

Because most emissions data has been collected under steady-state conditions (constant engine speed and load), and because most real-world operation involves transient conditions (variable speed and load), we attempt to adjust for the difference between laboratory measurements and real-world operation through the use of transient adjustment factors (TAFs). The TAF is a ratio representing the difference in the emission rate between transient and steady-state operation. The TAFs are estimated by collecting emissions measurements on specific engines using both transient and steady-state cycles, and calculating the ratio

$$TAF = \frac{EF_{transient}}{EF_{steady-state}}$$

where $EF_{transient}$ is the measurement for a given engine on a specific transient cycle, and $EF_{steady\text{-}state}$ is the corresponding measurement for the same engine on a selected steady-state cycle. Data from seven transient cycles were used to develop seven TAFs for each of the four pollutants. The seven cycle TAFs were then binned into two categories, based on the cycle load factors. TAFs were then assigned to each equipment type represented in the model on the basis of engineering judgment. If steady-state operation was typical of an equipment type, no adjustment was made (i.e., TAF = 1.0).

Emission factors in the model input file represent the product (ZHL·TAF) for each combination of equipment type, size class and regulatory tier represented by the model. We refer to this product as the "baseline emission factor." For more detail on the derivation and application of EFs and TAFs, refer to the model documentation on diesel emission factors[1].

During a model run, the model applies emissions deterioration to the baseline emission factor, based on the age distribution of the equipment type in the year simulated. Deterioration expresses an assumption that emissions increase with equipment age and is expressed as a multiplicative deterioration factor (DF). Thus, the final emission factor applied in the simulation year is the product ZHL·TAF·DF. Deterioration factors vary from year to year; we describe their calculation in more detail in subsection 3.1.1.2.2 below.

The model estimates fuel consumption by substituting brake-specific fuel consumption (BSFC, lb/hp-hr) for the emission factor in the equation above. We apply a TAF to the BSFC but assume that BSFC does not deteriorate with equipment age.

In estimation of PM emissions, we apply an additional adjustment to the emission factor to account for the in-use sulfur level of diesel fuel.[1] Based on user-specified diesel sulfur levels for a given scenario, NONROAD adjusts the PM emission factor by the margin S_{PMadj} (g/hp-hr) calculated as

$$S_{PMadj} = BSFC \cdot m_{SO4,S} \cdot m_{PM,S} \cdot 0.01 \cdot (S_{base} - S_{in-use})$$

where: BSFC = brake-specific fuel consumption (g fuel/hp-hr),

$m_{SO4,S}$ = a constant, representing the sulfate fraction of total particulate sulfur, equal to 7.0 g PM SO_4/g PM S,

$m_{PM,S}$ = a constant, representing the fraction of fuel sulfur converted to particulate sulfur, equal to 0.02247 g PM S/g fuel S,

0.01 = conversion factor from wt% to wt fraction

S_{base} = base sulfur level in NONROAD (0.33 wt%, 3300 ppm for pre-control and Tier 1 engines; 0.20 wt%, 2000 ppm for Tier 2-3 engines),

S_{in-use} = in-use diesel sulfur level as specified by user (wt%).

Equipment Activity. Activity represents the usage of equipment, expressed in operating hours per year. Activity estimates are specific to equipment types and remain constant in any given simulation year. Activity estimates for diesel equipment have been adopted from the *Partslink* model, a commercial source developed and maintained by Power Systems Research/Compass International, Inc. For discussion of activity estimates for specific equipment types, refer to the technical documentation for the model.[2]

Load Factor. This parameter represents the average fraction of rated power that equipment uses during operation. Load factors are assigned by equipment type, and remain constant in any simulation year. For use in draft NONROAD2002, we derived load factors from the results of a project designed to develop transient engine test cycles. During the course of the project, seven cycles were developed, designed to represent the operation of specific common equipment types.

Specific load factors for the cycles fell into two broad groups, which we designated as “high” and “low.” We calculated an average for each group, with the high group containing four cycles and the low group three; resulting load factors were 0.59 for the high group and 0.21 for the low group. Then, we assigned one of these two factors to each equipment type for which we believed engineering judgment was sufficient to make an assignment. For remaining equipment types, for which we considered engineering judgment insufficient to make an assignment, we assigned a ‘steady-state’ load factor, calculated as the average of load factors for all seven transient cycles (0.43). Of NONROAD’s 90 diesel applications, half were assigned ‘high’ or ‘low’ load factors, with the remainder assigned ‘steady-state’ load factors. For more detail on the derivation of load factors and assignment to specific equipment types, refer to the appropriate technical report[2].

Rated Power. This parameter represents the average rated power for equipment, as assigned to each combination of equipment type and rated-power class represented by the model. Values assigned to a given type/power combination represents the sales-weighted average of engines for that equipment type in that rated-power class.[3] Rated-power assignments remain constant in any given simulation year. For use in draft NONROAD2002, we obtained estimates from the *Partslink* database, maintained by Power Systems Research/Compass International, Inc. The product of load factor and rated power (*LP*) represents actual power output during equipment operation.

Equipment Population. As the name implies, this model input represents populations of equipment pieces. For diesel engines, the model generates separate sub-populations for individual combinations of equipment type and rated-power class. However, unlike activity and load factor, populations do not remain constant from year to year. Projection of future or past populations is the means through which the draft NONROAD2002 model projects future or past emissions. As a reference point, the input file contains populations in the model’s base year 1998. We generated populations in the base year using a simple attrition model that calculated base-year populations as a function of equipment sales, scrappage, activity and load factor. Equipment sales by model year were obtained from the commercially available *Partslink* database, developed and maintained by Power Systems Research/Compass International, Inc.

(PSR). This database contains sales estimates for nonroad equipment for model years 1973 through 1999. Base-year population development is discussed in the technical documentation.[3]

3.1.1.2.2 Projection Variables

The model uses three variables to project emissions over time: the annual population growth rate, the equipment median life, and the relative deterioration rate. Collectively, these variables represent population growth, changes in the equipment age distribution, and emissions deterioration.

Annual Population Growth Rate (%/year). The population growth rate represents the percentage increase in the equipment population for a given equipment type over successive years. The growth rate is linear for diesel equipment, and is applied to the entire population, including all rated-power classes and tiers[4]. Diesel growth rates vary by sector (e.g., agricultural, construction).

Equipment Median Life (hours @ full load). This variable represents the period of time over which 50% of the engines in a given "model-year cohort" are scrapped. A "model-year cohort" represents a sub-population of engines represented as entering the population in a given year. The input value assumes that (1) engines are run at full load until failure, and (2) equipment scrappage follows the model's scrappage curve. During a simulation, the model uses the "annualized median life," which represents the actual service life of equipment in years, depending on how much and how hard the equipment is used. Annualized median life is calculated as median life in hours (l_h), divided by the product of activity and load factor ($l_y = l_h/AL$). Engines persist in the equipment population over two median lives ($2l_y$); during the first median life, 50% of the engines are scrapped, and over the second, the remaining 50% are scrapped. For a more detailed description of median life, see the model documentation.[2]

Relative Deterioration Rate (% increase in emission factor/% median life expended). This variable plays a key role in calculation of the deterioration factor. Values of the relative deterioration rate are assigned based on pollutant, rated-power class, and tier. Using the relative deterioration rate (d), the annualized median life (l_y) and the equipment age, draft NONROAD2002 calculates the deterioration factor as

$$\mathrm{DF}_{\mathrm{pollutant,tier,year}} = 1 + d_{\mathrm{pollutant,tier}}\left(\frac{\mathrm{age}_{\mathrm{year}}}{l_y}\right)$$

where:

$\mathrm{DF}_{\mathrm{pollutant,year}}$ = the deterioration factor for a given pollutant for a model-year cohort in the simulation year,

d = the relative deterioration rate for a given pollutant (% increase in emission factor / % useful life expended) and regulatory tier,

age = the age of a specific model-year group of engines in the simulation year,

l_y = the annualized median life of the given model-year cohort (years).

The deterioration factor adjusts the exhaust emission factor for engines in a given model-year cohort in relation to the proportion of median life expended. The model calculates the deterioration linearly over one median life for a given model-year cohort (represented as a fraction of the entire population). Following the first median life, the deteriorated emission factor is held constant over the remaining life for engines in the cohort. The model's deterioration calculations are discussed in greater detail in the technical documentation.[1]

3.1.1.2.3 Scenario Option Variables

These inputs apply to entire model runs or scenarios, rather than to equipment. Scenario options describe fuel characteristics and ambient weather conditions. The option that applies to inventories for diesel equipment is the in-use diesel sulfur level (wt%).

The in-use diesel fuel sulfur level inputs used for land-based diesel engines for the baseline scenarios are provided in Table 3.1-1. The fuel sulfur levels account for spillover use of highway fuel and are discussed in more detail in Chapter 7.

Table 3.1-1
Modeled Baseline In-Use Diesel Fuel Sulfur Content
for Land-Based Nonroad Diesel Engines

Fuel Sulfur (ppm)	Calendar Year
2318	through 2005
2271	2006
2237	2007-2009
2217	2010+

3.1.1.3 Emissions Estimation Process

To project emissions in a given year, the draft NONROAD2002 model performs a series of steps (not necessarily in the order described).

Equipment Population. The model projects the equipment population for the user-specified simulation year. The current year's population (N_{year}) is projected as a function of the base-year population (N_{base}) as

$$N_{\text{year}} = N_{\text{base}}(1 + ng)$$

where g is the annual growth rate and n is the number of years between the simulation year and the base year. For diesel equipment, population projection follows a linear trend as in the equation above. Diesel growth rates in the model vary only by sector (e.g., agricultural, construction). The sector-specific growth rates are applied to all equipment types and hp categories within each sector.

Equipment Age Distribution. The model assigns an age distribution for each sub-population calculated in the previous step. This calculation divides the total population into a series of model-year cohorts of decreasing size, with the number of cohorts equal to twice the annualized median life for the rated-power class under consideration ($2l_y$). Each model-year cohort is estimated as a fraction of the total population, using fractions derived from NONROAD's scrappage curve, scaled to the useful life of the given rated-power class, also equal to $2l_y$.[5]

Emission and Deterioration Factors. Because the previous steps were performed for engines of a given rated-power class, the model assigns emission factors to different model year cohorts simply by relating equipment age to regulatory tier. Similarly, the model calculates deterioration factors for each cohort. The algorithm identifies the appropriate relative deterioration rate in relation to tier and rated-power class, calculates the age of the cohort, and supplies these inputs to the deterioration factor equation.

Activity and Load Factor. The model obtains the appropriate activity, load factor and rated power estimates. Activity and load factor are defined on the basis of equipment type alone; they are constant for all model-year cohorts, and rated power is determined on the basis of equipment type and rated power class.

Emissions Calculation. For a given pollutant, the calculations described above are performed and the resulting inputs multiplied in the exhaust emissions equation. The steps are repeated for each rated-power class within an equipment type to obtain total emissions for that type. The resulting subtotals for equipment types are then summed to obtain total emissions from all equipment types included in the simulation. These processes are repeated for each pollutant requested for the simulation. Using summation notation, the process may be summarized as

$$I_{\text{exh,poll}} = \overbrace{\sum \left[\overbrace{\sum \left(\overbrace{\sum \left(E_{\text{exh,poll}} \cdot A \cdot L \cdot P \cdot N \right)}^{\text{sum over all model-year cohorts within a rated-power class}} \right)}^{\text{sum over all rated-power classes within an equipment type}} \right]}^{\text{sum over all equipment types}}$$

3.1.1.4 Estimation of VOC Emissions

Volatile organic compounds are a class of hydrocarbons considered to be of regulatory interest. For purposes of inventory modeling, we define VOC as total hydrocarbon (THC) plus reactive oxygenated species, represented by aldehydes (RCHO) and alcohols (RCOH), less non-reactive species represented by methane and ethane (CH_4 and CH_3CH_3), as follows:

$$\mathrm{VOC} = \mathrm{THC} + (\mathrm{RCHO} + \mathrm{RCOH}) - (\mathrm{CH}_4 + \mathrm{CH}_3\mathrm{CH}_3)$$

The NONROAD model estimates VOC in relation to THC, where THC is defined as those hydrocarbons measured by a flame ionization detector (FID) calibrated to propane. Total hydrocarbon has exhaust and evaporative components, where the evaporative THC represents ‘crankcase emissions.’ Crankcase emissions are hydrocarbons that escape from the cylinder through the piston rings into the crankcase. The draft NONROAD2002 model assumes that all diesel engines have open crankcases, allowing that gases in the crankcase to escape to the atmosphere.

For diesel engines, the emission factor for crankcase emissions (EF_{crank}) is estimated as a fraction of the exhaust emission factor (EF_{exh}), as

$$\mathrm{EF}_{\mathrm{crank,HC,year}} = 0.02 \cdot \mathrm{EF}_{\mathrm{exh,HC,year}}$$

Note that the model adjusts crankcase emissions for deterioration. In a given simulation year, the crankcase emission factor is calculated from the deteriorated exhaust emission factor for that year, i.e., $EF_{exh,year} = ZHL \cdot TAF \cdot DF_{year}$.

The model estimates exhaust and crankcase VOC as a fraction of exhaust and crankcase THC, respectively.

$$\mathrm{VOC}_{\mathrm{exh}} = 1.053 \cdot \mathrm{THC}_{\mathrm{exh}}, \quad \mathrm{VOC}_{\mathrm{crank}} = 1.053 \cdot \mathrm{THC}_{\mathrm{crank}}$$

Note the fraction is greater than one, reflecting the addition of oxygenated species to THC. For additional discussion of the model’s estimation of crankcase and VOC emissions, refer to the model documentation.[1,6]

3.1.1.5 Estimation of SO_2 Emissions

To estimate SO_2 emissions, the draft NONROAD2002 model does not use an explicit emission factor. Rather, the model estimates a SO_2 emission factor EF_{SO2} on the basis of brake-specific fuel consumption, the user-defined diesel sulfur level, and the emission factor for THC.

$$\mathrm{EF}_{\mathrm{SO_2}} = \left[\mathrm{BSFC} \cdot (1 - m_{\mathrm{PM,S}}) - \mathrm{EF}_{\mathrm{THC}}\right] \cdot \mathrm{S}_{\mathrm{in-use}} \cdot m_{\mathrm{SO_2,S}}$$

where:

BSFC = brake-specific fuel consumption (g/hp-hr),

$m_{PM,S}$ = a constant, representing the fraction of fuel sulfur converted to particulate sulfur, equal to 0.02247 g PM S/g fuel S,

EF_{THC} = the in-use adjusted THC emission factor (g/hp-hr),
$S_{in\text{-}use}$ = the user-specified scenario-specific sulfur content of diesel fuel (weight fraction), and
$m_{SO2,S}$ = a constant, representing fraction of fuel sulfur converted to SO_2, equal to 2.0 g SO_2/g S.

This equation includes corrections for the fraction of sulfur that is converted to PM ($m_{PM,S}$) and for the sulfur remaining in the unburned fuel (EF_{THC}). The correction for unburned fuel, as indicated by THC emissions, is more significant for gasoline emissions, but insubstantial for diesel emissions.

Having estimated EF_{SO2}, the model estimates SO_2 emissions as it does other exhaust emissions.

3.1.1.6 Estimation of $PM_{2.5}$ Emissions

The model estimates emissions of diesel $PM_{2.5}$ as a multiple of PM_{10} emissions. $PM_{2.5}$ is estimated to compose 92% of PM_{10} emissions. This is based on an analysis of size distribution data for diesel vehicles.[7]

3.1.1.7 Estimation of Fuel Consumption

The draft NONROAD2002 model estimates fuel consumption using the equation

$$F = \frac{BSFC \cdot A \cdot L \cdot P \cdot N}{D}$$

where:
F = fuel consumption (gallons/year)
BSFC = brake-specific fuel consumption (lb/hp-hr)
A = equipment activity (operating hours/year)
L = load factor (average proportion of rated power used during operation (%))
P = average rated power (hp)
N = equipment population (units)
D = fuel density (lb/gal); diesel fuel density = 7.1 lb/gal

The fuel consumption estimates for land-based diesel and recreational marine diesel engines are given in Section 3.1.5.

3.1.1.8 Baseline Inventory

Tables 3.1-2a and 3.1-2b present the PM_{10}, $PM_{2.5}$, NO_x, SO_2, VOC, and CO baseline emissions for land-based nonroad engines in 1996 and 2000-2040, for the 48-state and 50-state inventories, respectively.

Table 3.1-2a
Baseline (48-State) Emissions for Land-Based Nonroad Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	191,858	176,510	1,583,664	147,926	221,403	1,010,518
2000	175,155	161,143	1,569,902	167,094	200,366	923,886
2001	169,360	155,811	1,556,973	171,957	191,785	886,722
2002	163,684	150,589	1,544,395	176,819	183,584	850,751
2003	157,726	145,108	1,522,881	181,677	176,201	817,858
2004	152,310	140,125	1,503,228	186,532	169,541	790,468
2005	147,050	135,286	1,483,942	191,385	163,193	764,918
2006	142,043	130,680	1,450,762	192,228	156,295	742,184
2007	138,140	127,089	1,414,673	194,003	149,518	724,213
2008	135,640	124,789	1,374,171	198,657	142,310	709,119
2009	133,495	122,815	1,331,986	203,311	135,259	695,970
2010	131,530	121,007	1,291,533	206,104	128,391	684,552
2011	130,288	119,865	1,255,472	210,737	122,161	675,805
2012	129,691	119,316	1,225,493	215,366	116,940	671,268
2013	129,674	119,300	1,202,185	219,992	112,619	670,147
2014	129,932	119,537	1,183,043	224,615	108,942	670,842
2015	130,388	119,957	1,167,635	229,235	105,800	672,944
2016	130,986	120,507	1,156,099	233,809	103,210	676,412
2017	131,765	121,224	1,147,635	238,381	101,137	681,217
2018	132,672	122,059	1,142,299	242,952	99,415	686,723
2019	133,767	123,065	1,140,236	247,521	97,952	692,845
2020	135,146	124,334	1,140,727	252,089	96,855	700,017
2021	136,655	125,723	1,143,660	256,656	96,055	707,986
2022	138,195	127,140	1,148,710	261,222	95,488	716,295
2023	139,797	128,613	1,155,440	265,786	95,170	724,914
2024	141,410	130,097	1,163,558	270,350	95,066	733,953
2025	143,091	131,644	1,172,971	274,913	95,144	743,434
2026	144,798	133,214	1,183,408	279,446	95,373	753,165
2027	146,471	134,753	1,194,643	283,978	95,729	763,023
2028	148,187	136,332	1,206,483	288,510	96,186	773,136
2029	149,915	137,922	1,218,884	293,042	96,724	783,449
2030	151,660	139,527	1,231,995	297,573	97,348	793,923
2031	153,451	141,175	1,245,794	302,104	98,059	804,566
2032	155,260	142,839	1,259,909	306,635	98,822	815,321
2033	157,088	144,521	1,274,280	311,165	99,628	826,151
2034	158,922	146,208	1,288,943	315,695	100,482	837,047
2035	160,748	147,888	1,303,901	320,226	101,380	847,953
2036	162,618	149,609	1,319,167	324,755	102,336	858,992
2037	164,511	151,350	1,334,609	329,285	103,325	870,072
2038	166,681	153,346	1,350,619	333,814	104,415	881,159
2039	168,853	155,345	1,366,795	338,344	105,529	892,281
2040	171,019	157,337	1,383,101	342,873	106,664	903,406

Table 3.1-2b
Baseline (50-State) Emissions for Land-Based Nonroad Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	192,750	177,330	1,592,025	148,729	222,517	1,015,773
2000	175,981	161,903	1,578,148	167,999	201,386	928,674
2001	170,165	156,552	1,565,144	172,889	192,765	891,304
2002	164,467	151,310	1,552,490	177,777	184,524	855,132
2003	158,487	145,808	1,530,854	182,662	177,107	822,062
2004	153,045	140,802	1,511,087	187,544	170,414	794,522
2005	147,761	135,940	1,491,692	192,424	164,035	768,838
2006	142,732	131,314	1,458,315	193,272	157,104	745,994
2007	138,814	127,708	1,422,017	195,057	150,293	727,946
2008	136,306	125,401	1,381,288	199,736	143,050	712,797
2009	134,154	123,422	1,338,867	204,416	135,965	699,604
2010	132,184	121,609	1,298,193	207,225	129,063	688,153
2011	130,942	120,466	1,261,939	211,884	122,803	679,389
2012	130,347	119,919	1,231,796	216,538	117,555	674,849
2013	130,335	119,908	1,208,367	221,189	113,212	673,736
2014	130,598	120,150	1,189,132	225,837	109,517	674,446
2015	131,060	120,575	1,173,656	230,483	106,359	676,570
2016	131,665	121,132	1,162,082	235,083	103,757	680,068
2017	132,452	121,856	1,153,602	239,680	101,676	684,911
2018	133,368	122,698	1,148,271	244,276	99,946	690,458
2019	134,470	123,713	1,146,227	248,870	98,478	696,625
2020	135,858	124,990	1,146,750	253,464	97,378	703,845
2021	137,377	126,387	1,149,727	258,056	96,575	711,863
2022	138,926	127,812	1,154,830	262,647	96,006	720,223
2023	140,537	129,294	1,161,619	267,237	95,688	728,896
2024	142,161	130,788	1,169,801	271,826	95,584	737,990
2025	143,853	132,345	1,179,283	276,414	95,663	747,528
2026	145,570	133,925	1,189,792	280,972	95,894	757,318
2027	147,254	135,474	1,201,104	285,529	96,253	767,234
2028	148,981	137,062	1,213,023	290,086	96,713	777,407
2029	150,719	138,662	1,225,506	294,643	97,255	787,780
2030	152,475	140,277	1,238,701	299,199	97,882	798,316
2031	154,278	141,936	1,252,586	303,755	98,598	809,021
2032	156,098	143,610	1,266,789	308,311	99,367	819,838
2033	157,937	145,302	1,281,249	312,867	100,178	830,731
2034	159,783	147,001	1,296,002	317,422	101,037	841,690
2035	161,621	148,691	1,311,051	321,977	101,940	852,660
2036	163,503	150,423	1,326,409	326,532	102,902	863,763
2037	165,407	152,174	1,341,945	331,087	103,898	874,908
2038	167,589	154,182	1,358,049	335,642	104,994	886,060
2039	169,774	156,192	1,374,321	340,196	106,114	897,248
2040	171,952	158,195	1,390,723	344,750	107,257	908,439

3.1.2 Land-Based Nonroad Diesel Engines—Air Toxics Emissions

EPA focused on 5 major air toxics pollutants for the proposed rule: benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and acrolein. These pollutants are VOCs and are included in the total land-based nonroad diesel VOC emissions estimate. EPA developed the baseline inventory estimates for these pollutants by multiplying the baseline VOC emissions from the draft NONROAD2002 model for a given year by the constant fractional amount that each air toxic pollutant contributes to VOC emissions. Table 3.1-3 shows the fractions that EPA used for each air toxics pollutant. EPA developed these nonroad air toxics pollutant fractions for the National Emissions Inventory.[8]

Table 3.1-3
Air Toxics Fractions of VOC

Benzene	Formaldehyde	Acetaldehyde	1,3-butadiene	Acrolein
0.020	0.118	0.053	0.002	0.003

Tables 3.1-4a and 3.1-4b show our 48-state and 50-state estimates of national baseline emissions for five selected major air toxic pollutants (benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and acrolein) for 1996, as well as for selected years from 2005 to 2030, modeled with the existing Tier 1-3 standards. Toxics emissions decrease over time until 2025 as engines meeting the Tier 1-3 standards are introduced into the fleet. Beyond 2025, the growth in population overtakes the effect of the existing emission standards. Chapter 2 discusses the health effects of these pollutants.

Table 3.1-4a
Baseline (48-State) Air Toxics Emissions
for Land-Based Nonroad Diesel Engines (short tons)

Year	Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
1996	4,428	26,126	11,734	443	664
2000	4,007	23,643	10,619	401	601
2005	3,264	19,257	8,649	326	490
2007	2,990	17,643	7,924	299	449
2010	2,568	15,150	6,805	257	385
2015	2,116	12,484	5,607	212	317
2020	1,937	11,429	5,133	194	291
2025	1,903	11,227	5,043	190	285
2030	1,947	11,487	5,159	195	292

Table 3.1-4b
Baseline (50-State) Air Toxics Emissions
for Land-Based Nonroad Diesel Engines (short tons)

Year	Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
1996	4,450	26,257	11,793	445	668
2000	4,028	23,764	10,673	403	604
2005	3,281	19,356	8,694	328	492
2007	3,006	17,735	7,966	301	451
2010	2,581	15,229	6,840	258	387
2015	2,127	12,550	5,637	213	319
2020	1,948	11,491	5,161	195	292
2025	1,913	11,288	5,070	191	287
2030	1,958	11,550	5,188	196	294

3.1.3 Commercial Marine Vessels and Locomotives

Although no new engine controls are being proposed for diesel commercial marine and locomotive engines, these engines do use diesel fuel and the effects of the proposed fuel changes need to be modeled. This section addresses the modeling of the baseline case for these engines, which includes effects of certain other rules such as (a) the April 1998 locomotive emissions final rule, (b) the December 1999 final rule for commercial marine diesel engines, and (c) the January 2001 heavy duty highway diesel fuel rule that takes effect in June 2006.

Since the draft NONROAD2002 model does not generate emission estimates for these applications, the emission inventories were calculated using the following methodology. VOC, CO, and NO_x emissions for 1996, 2020, and 2030 (the years chosen for air quality modeling) were taken from the existing HDDV inventory. These are presented in Table 3.1-5. Only 48-state emission estimates are available for these pollutants. VOC emissions in this inventory were calculated by multiplying THC emissions by a factor of 1.053, which is also the factor used for land-based diesel engines.

Table 3.1-5
Baseline (48-State) NO_x, VOC, and CO Emissions
for Locomotives and Commercial Marine Vessels (short tons)

Year	NO_x		VOC		CO	
	Locomotives	CMV	Locomotives	CMV	Locomotives	CMV
1996	921,556	959,704	48,381	31,545	112,171	126,382
2020	612,722	819,201	36,546	37,290	119,302	159,900
2030	534,520	814,827	31,644	41,354	119,302	176,533

The baseline SO_2 and PM emission inventory estimates were revised to reflect changes to the base sulfur levels. Tables 3.1-6a and 3.1-6b provide the 48-state and 50-state baseline fuel sulfur levels, $PM_{2.5}$, and SO_2 emissions. The fuel sulfur levels were calculated as weighted average in-use levels of (a) uncontrolled nonroad diesel fuel at 3400 ppm sulfur, (b) "spillover" of low sulfur highway diesel fuel into use by nonroad applications outside of California, and (c) full use of low sulfur California fuel in all nonroad applications in California. The slight decrease in average sulfur level in 2006 is due to the introduction of highway diesel fuel meeting the 2007 15 ppm standard, and the "spillover" of this highway fuel into the nonroad fuel pool. The derivation of the fuel sulfur levels is discussed in more detail in Chapter 7.

Locomotive diesel fuel volumes were calculated by the following methodology. Calendar year 2000 distillate fuel consumption for railroads was taken from the US Energy Information Administration (EIA) Fuel Oil & Kerosene Supply (FOKS) 2000 report. The volume of diesel fuel consumed by railroad was assumed to represent 95 percent of the reported distillate value. Also, the fuel volumes reported in FOKS appear to represent fuel usage by locomotives as well as by rail maintenance equipment, so the fuel consumption specific to locomotives was calculated by subtracting one percent, which is our estimate of rail maintenance fuel consumption, from the railroad diesel volume estimate. Calendar year 2001-2020 locomotive fuel consumption values were computed by multiplying the year 2000 fuel volume by a growth factor computed as the ratio of projected calendar year railroad sector energy consumption to year 2000 energy consumption from the EIA Annual Energy Outlook (AEO) 2002, Table 7, Transportation Sector, Key Indicators and Delivered Energy Consumption, Energy Use by Mode, Railroad. Calendar year 2021-2040 locomotive gallons were computed by growing the year 2000 locomotive fuel volume using the EIA/AEO 2000-2020 average annual compound growth of 0.892% (e.g., 2030CY growth factor = 1.00892^{30} = 1.305). The methodology for determining the locomotive diesel fuel consumption is further documented in Chapter 7. The locomotive diesel fuel consumption for 1996 was estimated by multiplying the calendar year 2000 locomotive fuel volume by the ratio of the FOKS railroad distillate fuel volumes for 1996 and 2000.

Table 3.1-6a
Baseline (48-State) Fuel Sulfur Levels, SO_2,
Sulfate PM, and $PM_{2.5}$ Emissions for Locomotives and Commercial Marine Vessels

Year	Locomotive Usage (10^9 gal/yr)	Commercial Marine Usage (10^9 gal/yr)	Base Sulfur Level (ppm)	Base						
				SO_2		Sulfate PM		PM_{10} EF Loco (g/gallon)	Total $PM_{2.5}$	
				Loco	CMV	Loco	CMV		Loco	CMV
1996	3.039	1.560	2396	50,534	25,948	4,066	2,088	6.8	20,937	36,366
2000	2.821	1.611	2396	46,911	26,791	3,774	2,155	6.8	19,436	37,186
2001	2.966	1.629	2396	49,328	27,083	3,969	2,179	6.8	20,438	37,397
2002	2.918	1.646	2396	48,521	27,379	3,904	2,203	6.8	20,103	37,608
2003	2.969	1.664	2396	49,366	27,679	3,972	2,227	6.8	20,453	37,819
2004	3.010	1.683	2396	50,047	27,983	4,026	2,251	6.8	20,735	38,031
2005	3.051	1.701	2396	50,738	28,291	4,082	2,276	6.6	20,403	38,243
2006	3.081	1.720	2352	50,288	28,078	4,046	2,259	6.4	19,977	38,416
2007	3.111	1.739	2321	50,109	28,015	4,031	2,254	6.2	19,541	38,601
2008	3.124	1.758	2321	50,331	28,326	4,049	2,279	6.0	18,994	38,813
2009	3.146	1.778	2321	50,679	28,638	4,077	2,304	5.9	18,807	39,026
2010	3.169	1.797	2302	50,625	28,718	4,073	2,310	5.7	18,300	39,221
2011	3.223	1.817	2302	51,487	29,036	4,142	2,336	5.7	18,612	39,434
2012	3.237	1.838	2302	51,720	29,359	4,161	2,362	5.6	18,368	39,647
2013	3.246	1.858	2302	51,861	29,686	4,172	2,388	5.5	18,089	39,860
2014	3.255	1.879	2302	52,006	30,019	4,184	2,415	5.4	17,809	40,074
2015	3.270	1.900	2302	52,240	30,356	4,203	2,442	5.3	17,559	40,288
2016	3.303	1.921	2302	52,776	30,698	4,246	2,470	5.2	17,404	40,503
2017	3.322	1.943	2302	53,079	31,045	4,270	2,498	5.1	17,167	40,718
2018	3.340	1.965	2302	53,355	31,397	4,293	2,526	5.1	17,257	40,933
2019	3.358	1.988	2302	53,655	31,754	4,317	2,555	5.0	17,013	41,149
2020	3.369	2.010	2302	53,832	32,117	4,331	2,584	4.9	16,728	41,365
2021	3.399	2.033	2302	54,312	32,485	4,370	2,614	4.8	16,533	41,767
2022	3.430	2.057	2302	54,796	32,859	4,409	2,644	4.7	16,333	42,171
2023	3.460	2.080	2302	55,285	33,239	4,448	2,674	4.7	16,478	42,574
2024	3.491	2.105	2302	55,778	33,624	4,488	2,705	4.6	16,272	42,978
2025	3.522	2.129	2302	56,276	34,016	4,528	2,737	4.5	16,060	43,382
2026	3.554	2.154	2302	56,778	34,413	4,568	2,769	4.4	15,843	43,787
2027	3.585	2.179	2302	57,285	34,817	4,609	2,801	4.4	15,985	44,192
2028	3.617	2.205	2302	57,796	35,227	4,650	2,834	4.3	15,761	44,598
2029	3.650	2.231	2302	58,311	35,644	4,691	2,868	4.2	15,531	45,004
2030	3.682	2.257	2302	58,832	36,068	4,733	2,902	4.2	15,670	45,411
2031	3.715	2.284	2302	59,356	36,498	4,775	2,936	4.1	15,433	45,818
2032	3.748	2.312	2302	59,886	36,936	4,818	2,972	4.0	15,191	46,226
2033	3.782	2.340	2302	60,420	37,380	4,861	3,007	4.0	15,327	46,634
2034	3.815	2.368	2302	60,959	37,832	4,904	3,044	3.9	15,077	47,043
2035	3.849	2.397	2302	61,503	38,292	4,948	3,081	3.9	15,211	47,453
2036	3.884	2.426	2302	62,052	38,759	4,992	3,118	3.9	15,347	47,863
2037	3.918	2.456	2302	62,605	39,235	5,037	3,157	3.8	15,087	48,273
2038	3.953	2.486	2302	63,164	39,718	5,082	3,195	3.8	15,222	48,684
2039	3.989	2.517	2302	63,727	40,210	5,127	3,235	3.7	14,953	49,096

2040	4.024	2.548	2302	64,296	40,710	5,173	3,275	3.7	15,087	49,509

Table 3.1-6b
Baseline (50-State) Fuel Sulfur Levels, SO_2, Sulfate PM, and $PM_{2.5}$ Emissions for Locomotives and Commercial Marine Vessels

Year	Locomotive Usage (10^9 gal/yr)	Commercial Marine Usage (10^9 gal/yr)	Base Sulfur Level (ppm)	Base						
				SO_2		Sulfate PM		PM_{10} EF Loco (g/gallon)	Total $PM_{2.5}$	
				Loco	CMV	Loco	CMV		Loco	CMV
1996	3.043	1.642	2396	50,604	27,297	4,071	2,196	6.8	20,966	38,257
2000	2.825	1.695	2396	46,976	28,184	3,779	2,267	6.8	19,463	39,119
2001	2.970	1.713	2396	49,396	28,491	3,974	2,292	6.8	20,466	39,340
2002	2.922	1.732	2396	48,589	28,802	3,909	2,317	6.8	20,131	39,563
2003	2.973	1.751	2396	49,434	29,118	3,977	2,343	6.8	20,482	39,785
2004	3.014	1.770	2396	50,116	29,437	4,032	2,368	6.8	20,764	40,008
2005	3.055	1.790	2396	50,808	29,762	4,088	2,394	6.6	20,432	40,231
2006	3.085	1.809	2352	50,358	29,538	4,051	2,376	6.4	20,004	40,413
2007	3.115	1.830	2321	50,178	29,471	4,037	2,371	6.2	19,568	40,608
2008	3.129	1.850	2321	50,401	29,798	4,055	2,397	6.0	19,021	40,831
2009	3.150	1.870	2321	50,749	30,127	4,083	2,424	5.9	18,833	41,054
2010	3.173	1.891	2302	50,695	30,210	4,079	2,431	5.7	18,325	41,259
2011	3.227	1.912	2302	51,559	30,545	4,148	2,457	5.7	18,637	41,483
2012	3.242	1.933	2302	51,792	30,885	4,167	2,485	5.6	18,393	41,708
2013	3.251	1.955	2302	51,933	31,229	4,178	2,512	5.5	18,114	41,932
2014	3.260	1.977	2302	52,078	31,579	4,190	2,541	5.4	17,834	42,157
2015	3.274	1.999	2302	52,313	31,934	4,209	2,569	5.3	17,583	42,382
2016	3.308	2.021	2302	52,849	32,293	4,252	2,598	5.2	17,428	42,608
2017	3.327	2.044	2302	53,153	32,658	4,276	2,627	5.1	17,191	42,834
2018	3.344	2.067	2302	53,429	33,029	4,299	2,657	5.1	17,281	43,061
2019	3.363	2.091	2302	53,729	33,405	4,323	2,688	5.0	17,037	43,288
2020	3.374	2.115	2302	53,906	33,787	4,337	2,718	4.9	16,751	43,515
2021	3.404	2.139	2302	54,387	34,174	4,376	2,749	4.8	16,556	43,939
2022	3.434	2.164	2302	54,872	34,567	4,415	2,781	4.7	16,355	44,363
2023	3.465	2.189	2302	55,362	34,967	4,454	2,813	4.7	16,501	44,787
2024	3.496	2.214	2302	55,856	35,372	4,494	2,846	4.6	16,294	45,212
2025	3.527	2.240	2302	56,354	35,784	4,534	2,879	4.5	16,082	45,637
2026	3.559	2.266	2302	56,857	36,202	4,574	2,913	4.4	15,865	46,063
2027	3.590	2.292	2302	57,364	36,627	4,615	2,947	4.4	16,007	46,490
2028	3.622	2.320	2302	57,876	37,059	4,656	2,981	4.3	15,782	46,916
2029	3.655	2.347	2302	58,392	37,497	4,698	3,017	4.2	15,553	47,344
2030	3.687	2.375	2302	58,913	37,943	4,740	3,053	4.2	15,692	47,772
2031	3.720	2.403	2302	59,439	38,396	4,782	3,089	4.1	15,455	48,200
2032	3.753	2.432	2302	59,969	38,856	4,825	3,126	4.0	15,212	48,629
2033	3.787	2.461	2302	60,504	39,323	4,868	3,164	4.0	15,348	49,059
2034	3.821	2.491	2302	61,044	39,799	4,911	3,202	3.9	15,098	49,489
2035	3.855	2.521	2302	61,588	40,282	4,955	3,241	3.9	15,233	49,919
2036	3.889	2.552	2302	62,138	40,774	4,999	3,280	3.9	15,368	50,351
2037	3.924	2.583	2302	62,692	41,274	5,044	3,321	3.8	15,108	50,783

2038	3.959	2.615	2302	63,252	41,783	5,089	3,362	3.8	15,243	51,215
2039	3.994	2.648	2302	63,816	42,300	5,134	3,403	3.7	14,974	51,648
2040	4.030	2.680	2302	64,385	42,826	5,180	3,445	3.7	15,108	52,082

Vessel bunkering (commercial and recreational marine) distillate fuel consumption for calendar year 2000 was also taken from the EIA FOKS 2000 report. The volume of diesel fuel consumed by vessel bunkering was assumed to represent 90 percent of the reported distillate value. The fuel consumption specific to commercial marine was then calculated by subtracting the recreational marine fuel consumption as generated by the draft NONROAD2002 model. Calendar year 2001-2040 commercial marine diesel fuel consumption values were computed by multiplying the year 2000 volume by the growth factor of CO emission projections for the combination of Category 1 and 2 vessels in the 2002 diesel marine engine final rule. CO emission projections were used due to availability and applicability as an appropriate surrogate for fuel consumption. The commercial marine diesel fuel consumption for 1996 was estimated by multiplying the calendar year 2000 commercial marine fuel volume by the ratio of the CO emission projections for 1996 and 2000.

Annual SO_2 emission estimates for locomotives and commercial marine vessels were calculated by multiplying the gallons of fuel use by the fuel density, the fuel sulfur content, and the molecular weight ratio of SO_2 to sulfur. This is then reduced by the fraction of fuel sulfur that is converted to sulfate PM (2.247% on average for engines without aftertreatment).[1] Following is an example of the calculation for the case when fuel sulfur content is 2300 ppm.

SO_2 tons = gallons × 7.1 lb/gallon × 0.0023 S wt. Fraction × (1-0.02247 S fraction converted to SO_2) × 64/32 SO_2 to S M.W. ratio / 2000 lb/ton

Unlike the equation used in the draft NONROAD2002 model for land-based diesel and recreational marine diesel engines (described in Section 3.1.1.5), this equation does not include a correction for the sulfur remaining in the unburned fuel. The correction for unburned fuel, as indicated by THC emissions, is not used for two reasons: 1) THC emission factors were not available for years other than 1996, 2020, and 2030, and 2) this correction factor is insubstantial for diesel emissions.

Annual sulfate PM emission estimates for locomotives and commercial marine vessels were calculated by multiplying the gallons of fuel use by the fuel density, the fuel sulfur content, the molecular weight ratio of hydrated sulfate to sulfur, and the fraction of fuel sulfur converted to sulfate on average. Following is an example of the calculation for the case when fuel sulfur content is 2300 ppm.

Sulfate tons = gallons × 7.1 lb/gallon × 0.0023 S wt. Fraction × 0.02247 fraction of S converted to sulfate × 224/32 sulfate to S M.W. ratio / 2000 lb/ton

Annual total PM_{10} emission estimates for locomotives were calculated by multiplying the gallons of fuel use by the gram per gallon PM emission factor from the 1998 locomotive final rule Regulatory Support Document. Following is an example calculation:

PM_{10} tons = gallons × g/gal EF / 454g/lb / 2000 lbs/ton

PM_{10} is assumed to be equivalent to total PM, and $PM_{2.5}$ is estimated by multiplying PM_{10} emissions by a factor of 0.92. This is the factor used for all nonroad diesel engines; the basis is described in Section 3.1.1.6.

Annual PM_{10} emission estimates for commercial marine vessels in calendar years 1996 and 2000 were taken from the inventory done for the HD07 rule. For years 2001 - 2030, the year 2000 inventory was adjusted according to the commercial marine growth factor mentioned above from the 2002 diesel marine engine final rule. The fuel sulfate portion was then adjusted to account for the revised sulfur levels.

3.1.4 Recreational Marine Engines

Diesel recreational marine engines consist mainly of inboard engines used in larger power boats and sailboats, but there are also a small number of outboard diesel engines in use. Emission estimates for this category were generated using the draft NONROAD2002 model. Details of the modeling inputs (e.g., populations, activity, and emission factors) for these engines can be found in the technical reports documenting the draft NONROAD2002 model. The emission inventory numbers presented here assume that recreational marine applications would use diesel fuel with the same sulfur content and sulfur-to-sulfate conversion rate as locomotives and commercial marine vessels.

It should be noted that these inventory values do not account for the newest standards promulgated in September 2002, which take effect in 2006-2009, for diesel recreational marine engines greater than 37 kw (50 hp). Although those standards provide substantial benefits for the affected engines (e.g., 25% - 37% reductions of PM, NO_x, and HC in 2030), the impact of this on the total nonroad diesel inventory is quite small, representing less than 1% of the baseline nonroad diesel inventory (without locomotives or commercial marine) for PM, NO_x, and HC in 2030.

Tables 3.1-7a and 3.1-7b present the PM_{10}, $PM_{2.5}$, NO_x, SO_2, VOC, and CO emissions for recreational marine engines in 1996 and 2000-2040 for the 48-state and 50-state inventories, respectively.

Table 3.1-7a
Baseline (48-State) Emissions for Recreational Marine Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	529	487	19,440	2,251	803	3,215
2000	594	547	21,899	2,537	900	3,613
2001	611	562	22,548	2,613	923	3,713
2002	627	577	23,196	2,689	947	3,814
2003	643	592	23,844	2,765	970	3,913
2004	660	607	24,492	2,841	992	4,013
2005	676	622	25,139	2,917	1,015	4,112
2006	688	633	25,790	2,939	1,037	4,211
2007	700	644	26,439	2,974	1,059	4,309
2008	716	659	27,088	3,049	1,081	4,406
2009	732	673	27,736	3,123	1,102	4,503
2010	745	686	28,384	3,171	1,124	4,599
2011	760	700	29,028	3,244	1,145	4,695
2012	776	714	29,671	3,317	1,166	4,790
2013	791	728	30,314	3,390	1,186	4,884
2014	806	741	30,957	3,463	1,207	4,979
2015	821	755	31,600	3,536	1,227	5,072
2016	836	769	32,244	3,610	1,247	5,166
2017	851	783	32,888	3,683	1,268	5,260
2018	865	796	33,531	3,756	1,288	5,353
2019	880	810	34,174	3,830	1,308	5,445
2020	895	823	34,817	3,903	1,328	5,538
2021	909	837	35,460	3,976	1,347	5,630
2022	924	850	36,103	4,050	1,367	5,722
2023	938	863	36,746	4,123	1,387	5,814
2024	953	877	37,388	4,196	1,406	5,906
2025	967	890	38,031	4,270	1,426	5,997
2026	982	903	38,673	4,343	1,446	6,089
2027	996	917	39,316	4,416	1,465	6,181
2028	1,011	930	39,959	4,489	1,486	6,275
2029	1,026	944	40,604	4,563	1,507	6,370
2030	1,042	958	41,250	4,636	1,528	6,465
2031	1,057	973	41,896	4,709	1,550	6,561
2032	1,072	987	42,543	4,782	1,571	6,656
2033	1,088	1,001	43,189	4,856	1,592	6,752
2034	1,103	1,015	43,836	4,929	1,614	6,848
2035	1,119	1,029	44,483	5,002	1,636	6,945
2036	1,134	1,044	45,131	5,075	1,658	7,041
2037	1,150	1,058	45,779	5,149	1,680	7,139
2038	1,166	1,073	46,428	5,222	1,703	7,238
2039	1,182	1,087	47,076	5,295	1,725	7,336
2040	1,198	1,102	47,725	5,368	1,748	7,435

Table 3.1-7b
Baseline (50-State) Emissions for Recreational Marine Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	532	490	19,562	2,265	808	3,236
2000	598	550	22,036	2,553	906	3,635
2001	615	566	22,689	2,629	929	3,737
2002	631	581	23,342	2,706	953	3,838
2003	648	596	23,994	2,783	976	3,938
2004	664	611	24,646	2,859	999	4,038
2005	680	626	25,297	2,936	1,021	4,138
2006	692	637	25,952	2,957	1,044	4,237
2007	705	648	26,605	2,993	1,066	4,336
2008	721	663	27,258	3,068	1,088	4,434
2009	736	677	27,911	3,142	1,109	4,531
2010	750	690	28,563	3,191	1,131	4,628
2011	765	704	29,210	3,264	1,152	4,724
2012	781	718	29,858	3,338	1,173	4,820
2013	796	732	30,505	3,411	1,194	4,915
2014	811	746	31,152	3,485	1,214	5,010
2015	826	760	31,798	3,559	1,235	5,104
2016	841	774	32,446	3,632	1,255	5,199
2017	856	787	33,094	3,706	1,276	5,293
2018	871	801	33,742	3,780	1,296	5,386
2019	886	815	34,389	3,854	1,316	5,480
2020	900	828	35,036	3,928	1,336	5,573
2021	915	842	35,683	4,001	1,356	5,665
2022	930	855	36,330	4,075	1,376	5,758
2023	944	869	36,977	4,149	1,395	5,850
2024	959	882	37,623	4,223	1,415	5,943
2025	973	895	38,270	4,297	1,435	6,035
2026	988	909	38,916	4,370	1,455	6,127
2027	1,003	922	39,563	4,444	1,475	6,220
2028	1,018	936	40,210	4,518	1,495	6,314
2029	1,033	950	40,860	4,591	1,516	6,410
2030	1,048	964	41,510	4,665	1,538	6,506
2031	1,064	979	42,160	4,739	1,559	6,602
2032	1,079	993	42,810	4,812	1,581	6,698
2033	1,095	1,007	43,461	4,886	1,602	6,795
2034	1,110	1,021	44,112	4,960	1,624	6,891
2035	1,126	1,036	44,763	5,034	1,646	6,988
2036	1,141	1,050	45,414	5,107	1,668	7,086
2037	1,157	1,065	46,067	5,181	1,691	7,184
2038	1,173	1,079	46,719	5,255	1,713	7,283
2039	1,189	1,094	47,372	5,328	1,736	7,382
2040	1,205	1,109	48,025	5,402	1,759	7,482

3.1.5 Fuel Consumption for Nonroad Diesel Engines

Table 3.1-8 presents the fuel consumption estimates for the land-based, recreational marine, locomotive, and commercial marine nonroad diesel categories. Fuel consumption estimates are provided for 1996 and 2000-2040 for the 48-state and 50-state inventories.

The fuel consumption estimates for land-based diesel and recreational marine diesel engines were obtained using the draft NONROAD2002 model. The methodology is described in Section 3.1.1.7. The derivation of the fuel consumption estimates for locomotives and commercial marine vessels is described in Section 3.1.3.

Some of the estimates in Table 3.1-8 are different than those presented in Chapter 7, which are ultimately used in estimating the cost of the proposed fuel regulations. As described above, the diesel fuel consumption volumes for land-based nonroad engines in this chapter were obtained from the draft NONROAD2002 model. In Chapter 7, land-based diesel fuel consumption demand was developed from an independent source of fuel consumption information. Specifically, those estimates are based primarily on data contained in the EIA FOKS 2000 report. That document broadly reports fuel sales for all uses, including stationary sources. Therefore, a number of assumptions must be applied to the information contained in FOKS 2000 to obtain an estimate of diesel fuel for nonroad engines.

When comparing the two methods of developing fuel consumption estimates, there is some difference in the results. Rather than adopt one of the two for all uses, we have decided to maintain the NONROAD2002 based estimates for inventory generation and the land-based diesel fuel estimates of Chapter 7 for the cost analyses. Use of the nonroad estimates for cost or the Chapter 7 estimates for emissions would introduce internal inconsistencies in the resulting cost or inventory results. These two estimates differ by a relatively small amount, approximately 15 percent in 2030, so we decided that maintaining consistency within the emissions modeling and within the cost estimation was preferable to enforcing consistency between these two areas. The Agency will continue to investigate how to resolve the differences between the two approaches for the final rule, if appropriate.

Although the locomotive diesel demand volumes in this chapter are identical to those described in Chapter 7, the marine diesel volumes are slightly different. In Chapter 7, the marine end-use category is a combination of both commercial and recreational marine end uses. In this chapter, recreational marine demand is estimated separately with the draft NONROAD2002 model for each calendar year, and subtracted from the respective combined marine end use volume to produce the commercial marine estimate. Also, the combined marine volume estimates in the two chapters differ by about one percentage for years prior to 2008 due to the use of a slightly different computational methodology for that period.

Table 3.1-8
Fuel Consumption for Nonroad Diesel Engines

Year	Fuel Consumption (10^6 gal/year)							
	Land-Based Diesel		Recreational Marine		Locomotives		Commercial Marine	
	48-State	50-State	48-State	50-State	48-State	50-State	48-State	50-State
1996	9,254	9,304	136	136	3,039	3,043	1,560	1,642
2000	10,440	10,496	153	154	2,821	2,825	1,611	1,695
2001	10,740	10,798	157	158	2,966	2,970	1,629	1,713
2002	11,040	11,100	162	163	2,918	2,922	1,646	1,732
2003	11,340	11,401	167	168	2,969	2,973	1,664	1,751
2004	11,640	11,703	171	172	3,010	3,014	1,683	1,770
2005	11,940	12,005	176	177	3,051	3,055	1,701	1,790
2006	12,238	12,304	180	181	3,081	3,085	1,720	1,809
2007	12,535	12,603	185	186	3,111	3,115	1,739	1,830
2008	12,833	12,903	190	191	3,124	3,129	1,758	1,850
2009	13,131	13,202	194	195	3,146	3,150	1,778	1,870
2010	13,429	13,502	199	200	3,169	3,173	1,797	1,891
2011	13,728	13,803	203	205	3,223	3,227	1,817	1,912
2012	14,028	14,104	208	209	3,237	3,242	1,838	1,933
2013	14,327	14,405	212	214	3,246	3,251	1,858	1,955
2014	14,627	14,706	217	218	3,255	3,260	1,879	1,977
2015	14,926	15,007	222	223	3,270	3,274	1,900	1,999
2016	15,223	15,306	226	228	3,303	3,308	1,921	2,021
2017	15,519	15,604	231	232	3,322	3,327	1,943	2,044
2018	15,816	15,902	235	237	3,340	3,344	1,965	2,067
2019	16,112	16,200	240	242	3,358	3,363	1,988	2,091
2020	16,409	16,498	245	246	3,369	3,374	2,010	2,115
2021	16,706	16,797	249	251	3,399	3,404	2,033	2,139
2022	17,002	17,095	254	255	3,430	3,434	2,057	2,164
2023	17,299	17,393	258	260	3,460	3,465	2,080	2,189
2024	17,595	17,691	263	265	3,491	3,496	2,105	2,214
2025	17,892	17,989	268	269	3,522	3,527	2,129	2,240
2026	18,186	18,286	272	274	3,554	3,559	2,154	2,266
2027	18,481	18,582	277	279	3,585	3,590	2,179	2,292
2028	18,776	18,878	281	283	3,617	3,622	2,205	2,320
2029	19,070	19,175	286	288	3,650	3,655	2,231	2,347
2030	19,365	19,471	291	292	3,682	3,687	2,257	2,375
2031	19,660	19,767	295	297	3,715	3,720	2,284	2,403
2032	19,954	20,063	300	302	3,748	3,753	2,312	2,432
2033	20,249	20,358	304	306	3,782	3,787	2,340	2,461
2034	20,544	20,656	309	311	3,815	3,821	2,368	2,491
2035	20,838	20,952	314	315	3,849	3,855	2,397	2,521
2036	21,133	21,249	318	320	3,884	3,889	2,426	2,552
2037	21,428	21,545	323	325	3,918	3,924	2,456	2,583
2038	21,722	21,841	327	329	3,953	3,959	2,486	2,615
2039	22,017	22,137	332	334	3,989	3,994	2,517	2,648
2040	22,312	22,434	336	339	4,024	4,030	2,548	2,680

3.2 Contribution of Nonroad Diesel Engines to National Emission Inventories

This section provides the contribution of nonroad diesel engines to national baseline emission inventories in 1996, 2020, and 2030. The emission inventories are based on 48-state inventories that exclude Alaska and Hawaii in order to be consistent with the air quality modeling region. The baseline cases represent current and future emissions with only the existing standards. For nonroad engines, the baseline inventories were developed prior to promulgation of standards that cover large spark-ignition engines (>25 hp), recreational equipment, and recreational marine diesel engines (>50 hp).[9] Although the future inventories presented here do not account for the impact of the standards for those nonroad categories, qualitative impacts of those standards on the inventories will be discussed. We intend to account for the impact of these standards in the final rule analysis.

The calendar years correspond to those chosen for the air quality modeling. Pollutants discussed include $PM_{2.5}$, NO_x, SO_2, VOC, and CO. VOC includes both exhaust and evaporative emissions.

Of interest are the contributions of emissions from nonroad diesel sources affected by the proposed rule. For $PM_{2.5}$ and SO_2, this includes emissions from all nonroad diesel sources. For NO_x, VOC, and CO, this includes emissions from land-based nonroad diesel engines. Contributions to both total mobile source emissions and total emissions from all sources are presented. For $PM_{2.5}$, contributions of nonroad diesel engines to both total diesel $PM_{2.5}$ and total manmade $PM_{2.5}$ are also presented.

The development of the 1996, 2020, and 2030 baseline emissions inventories for the nonroad sector and for the sectors not affected by this proposed rule will be briefly described, followed by discussions for each pollutant of the contribution of nonroad diesel engines to national baseline inventories.

3.2.1 Baseline Emissions Inventory Development

For 1996, 2020, and 2030, county-level emission estimates were developed by Pechan under contract to EPA. These were used as input for the air quality modeling. These inventories account for county-level differences in parameters such as fuel characteristics and temperature. The draft NONROAD2002 model was used to generate the county-level emissions estimates for all nonroad sources, with the exception of commercial marine engines, locomotives, and aircraft. The methodology has been documented elsewhere.[10]

The on-highway estimates are based on the MOBILE5b model, but with some further adjustments to reflect MOBILE6 emission factors. The on-highway inventories are similar to those prepared for the Heavy-Duty Diesel (HDD) rulemaking [11], with the exception of adjustments to NO_x and VOC for California counties, based on county-level estimates from the California Air Resources Board.

The stationary point and area source estimates are also based on the HDD rulemaking, with the exception of adjustments to NO_x and VOC for California counties, based on county-level estimates from the California Air Resources Board. There were also some stack parameter corrections made to the point source estimates.

The model inputs for the diesel nonroad sources have been described in detail in Section 3.1. Although county-level-based inventories were developed by Pechan for the land-based diesel and recreational marine diesel categories, these were not used in this section. Instead, the emission estimates for these categories were based on national level runs. This was done for two reasons. First, the baseline inventories for 2020 and 2030 were revised since the county-level estimates were developed (specifically, $PM_{2.5}$ and SO_2 emissions were changed to reflect revised diesel fuel sulfur inputs). It was not possible to develop revised county-level estimates for these categories due to resource and time constraints. Second, county-level estimates were only developed for 2020 and 2030. Estimates for interim years are also needed to fully evaluate the anticipated emission benefits of the proposed rule. Interim year estimates are generated using national level model runs. In order to be consistent with other sections of the RIA in which interim year estimates from 1996 to 2030 are presented, the inventory estimates presented here for the land-based diesel and recreational marine diesel categories are based on national level model runs. Model results for national level runs are similar to those based on an aggregation of county-level runs. For a more detailed comparison of national level and county level results, see Section 3.6.

3.2.2 $PM_{2.5}$ Emissions

Table 3.2-1 provides the contribution of land-based diesel engines and other source categories to total diesel $PM_{2.5}$ emissions.

$PM_{2.5}$ emissions from land-based nonroad diesels are 43% of the total diesel $PM_{2.5}$ emissions in 1996, and this percentage increases to 64% by 2030. Emissions from land-based nonroad diesels actually decrease from 176,510 tons in 1996 to 124,334 tons in 2020 due to the existing emission standards. From 2020 to 2030, however, emissions increase to 139,527 tons, as growth in this sector offsets the effect of the existing emission standards.

$PM_{2.5}$ emissions from recreational marine diesel engines, commercial marine diesel engines, and locomotives will also be affected by this proposal due to the fuel sulfur requirements. For all nonroad diesel sources affected by this proposal, the contribution to total diesel $PM_{2.5}$ emissions increases from 57% in 1996 to 92% in 2030.

Table 3.2-2 provides the contribution of land-based diesel engines and other source categories to total manmade $PM_{2.5}$ emissions. $PM_{2.5}$ emissions from land-based nonroad diesels are 8% of the total manmade $PM_{2.5}$ emissions in 1996, and this percentage drops slightly to 6% in 2020 and 2030. The contribution of land-based diesels to total mobile source $PM_{2.5}$ emissions is 32% in 1996, rising to 37% by 2030. For all nonroad diesel sources, the contribution to total manmade $PM_{2.5}$ emissions is 11% in 1996, and this percentage drops slightly to 9% in 2020 and 2030.

The recently promulgated standards for large spark-ignition engines, recreational equipment, and recreational marine diesel engines (>50 hp) include PM standards for the recreational equipment and recreational marine diesel categories. $PM_{2.5}$ emissions from recreational equipment would be reduced roughly 50% by 2030, whereas $PM_{2.5}$ emissions from recreational marine diesel engines over 50 hp would be reduced roughly 25% by 2030 with these standards. Since $PM_{2.5}$ emissions from recreational equipment and recreational marine diesel engines constitute less than 1% of the total emissions, the impact of these PM standards will have a negligible effect on the inventories provided in Tables 3.2-1 and 3.2-2.

3.2.3 NO_x Emissions

Table 3.2-3 provides the contribution of land-based diesel engines and other source categories to total NO_x emissions.

NO_x emissions from land-based nonroad diesels are 6% of the total emissions in 1996, and this percentage increases to 8% by 2030. The contribution of land-based diesels to total mobile source NO_x emissions is 12% in 1996, rising to 24% by 2030. Emissions from land-based nonroad diesels actually decrease from 1,583,664 tons in 1996 to 1,140,727 tons in 2020 due to the existing emission standards. From 2020 to 2030, however, emissions increase to 1,231,995 tons, as growth in this sector offsets the effect of the existing emission standards.

NO_x emissions from recreational marine diesel engines, commercial marine diesel engines, and locomotives will not be affected by this proposal. For these categories combined, the contribution to total NO_x emissions remains stable at 9% from 1996 to 2030.

The recently promulgated standards for large spark-ignition engines, recreational equipment, and recreational marine diesel engines (>50 hp) include NO_x standards for the recreational marine diesel and large spark-ignition categories. NO_x emissions from recreational marine diesel engines over 50 hp would be reduced roughly 25% by 2030, whereas NO_x emissions from large spark-ignition engines would be reduced roughly 90% by 2030 with these standards. Although the contribution from these categories will decrease due to the standards, the contribution of land-based diesel engines to the total NO_x inventory remains stable at 8% in 2030.

3.2.4 SO_2 Emissions

Table 3.2-4 provides the contribution of land-based diesel engines and other source categories to total SO_2 emissions.

SO_2 emissions from land-based nonroad diesels are 1% of the total emissions in 1996, and this percentage increases to 2% by 2030. The contribution of land-based diesels to total mobile source SO_2 emissions is 20% in 1996, rising to 44% by 2030, due to continued growth in this sector.

SO_2 emissions from recreational marine diesel engines, commercial marine diesel engines, and locomotives will also be affected by this proposal due to the fuel sulfur requirements. For all nonroad diesel sources affected by this proposal, the contribution to total SO_2 emissions increases from 1% in 1996 to 3% in 2030.

The recently promulgated standards for large spark-ignition engines, recreational equipment, and recreational marine diesel engines (>50 hp) do not impact SO_2 emissions; therefore, the SO_2 emissions inventories presented in Table 3.2-4 are not affected by these standards.

3.2.5 VOC Emissions

Table 3.2-5 provides the contribution of land-based diesel engines and other source categories to total VOC emissions. VOC includes both exhaust and evaporative emissions. VOC is an ozone precursor; therefore, VOC inventories are required for air quality modeling.

VOC emissions from land-based nonroad diesels are 1% of the total emissions in 1996, and this percentage remains stable at 1% by 2030. The contribution of land-based diesels to total mobile source VOC emissions is 3% in 1996, decreasing slightly to 2% by 2030. Emissions from land-based nonroad diesels actually decrease from 221,403 tons in 1996 to 96,855 tons in 2020 due to the existing emission standards. From 2020 to 2030, however, emissions increase to 97,348 tons, as growth in this sector offsets the effect of the existing emission standards.

VOC emissions from recreational marine diesel engines, commercial marine diesel engines, and locomotives will not be affected by this proposal. For these categories combined, the contribution to total VOC emissions increases slightly from 1% from 1996 to 2% in 2030.

The recently promulgated standards for large spark-ignition engines, recreational equipment, and recreational marine diesel engines (>50 hp) include VOC standards for each category. VOC emissions from large spark-ignition engines would be reduced roughly 65% by 2030 with these standards. VOC emissions from recreational equipment would be reduced roughly 70%, whereas VOC emissions from recreational marine diesel engines over 50 hp would be reduced roughly 35% by 2030. Although the contribution from these categories will decrease due to the standards, the contribution of land-based diesel engines to the total VOC inventory remains stable at 1% in 2030.

3.2.6 CO Emissions

Table 3.2-6 provides the contribution of land-based diesel engines and other source categories to total CO emissions.

CO emissions from land-based nonroad diesels are 1% of the total emissions in 1996, and this percentage remains stable at 1% by 2030. The contribution of land-based diesels to total mobile source CO emissions is also 1% in 1996, remaining at 1% by 2030. Emissions from land-based nonroad diesels actually decrease from 1,010,518 tons in 1996 to 700,017 tons in 2020 due to the existing emission standards. From 2020 to 2030, however, emissions increase to 793,923 tons, as growth in this sector offsets the effect of the existing emission standards.

CO emissions from recreational marine diesel engines, commercial marine diesel engines, and locomotives will not be affected by this proposal. For these categories combined, the contribution to total CO emissions is less than 1% in 1996 and 2030.

The recently promulgated standards for large spark-ignition engines, recreational equipment, and recreational marine diesel engines (>50 hp) include CO standards for the large spark-ignition and recreational equipment categories. CO emissions from large spark-ignition engines would be reduced roughly 90% by 2030 with these standards, whereas CO emissions from recreational equipment would be reduced roughly 20% by 2030. Although the contribution from these categories will decrease due to the standards, the contribution of land-based diesel engines to the total CO inventory remains stable at 1% in 2030.

Table 3.2-1
Annual Diesel $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories[a]

Category	1996			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Land-Based Nonroad Diesel	176,510	43.9%	42.6%	124,334	61.7%	60.4%	139,527	64.7%	63.5%
Recreational Marine Diesel ≤50 hp	62	0.0%	0.0%	70	0.0%	0.0%	64	0.0%	0.0%
Recreational Marine Diesel >50 hp [b]	425	0.1%	0.1%	753	0.4%	0.4%	894	0.4%	0.4%
Commercial Marine Diesel	36,367	9.1%	8.8%	41,365	20.5%	20.1%	45,411	21.1%	20.7%
Locomotive	20,937	5.2%	5.1%	16,727	8.3%	8.1%	15,670	7.3%	7.1%
Total Nonroad Diesel	234,301	58%	57%	183,249	91%	89%	201,566	94%	92%
Total Highway Diesel	167,384	42%	40%	18,426	9%	9%	13,948	6%	6%
Total Mobile Source Diesel	401,685	100%	97%	201,675	100%	98%	215,514	100%	98%
Stationary Point and Area Source Diesel [c]	12,199	—	3%	4,010	—	2%	4,231	—	2%
Total Man-Made Diesel Sources	413,884	—		205,685	—		219,745	—	
Mobile Source Percent of Total	97%	—		98%	—		98%	—	

[a] These are 48-state inventories. They do not include Alaska and Hawaii.

[b] These inventories do not account for the final rule to control emissions from nonroad large spark-ignition engines, recreational marine diesel engines >50 hp, and recreational vehicles, published November 8, 2002.

[c] This category includes point sources burning either diesel, distillate oil (diesel), or diesel/kerosene fuel.

Table 3.2-2
Annual $PM_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories [a,b]

Category	1996			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Land-Based Nonroad Diesel	176,510	31.5%	8.0%	124,334	35.4%	6.0%	139,527	36.7%	6.3%
Recreational Marine Diesel ≤50 hp	62	0.0%	0.0%	70	0.0%	0.0%	64	0.0%	0.0%
Recreational Marine Diesel >50 hp [c]	425	0.1%	0.0%	753	0.2%	0.0%	894	0.2%	0.0%
Recreational Marine SI	35,147	6.3%	1.6%	26,110	7.4%	1.3%	27,223	7.2%	1.2%
Nonroad SI ≤25 hp	24,130	4.3%	1.1%	29,998	8.5%	1.5%	34,435	9.1%	1.6%
Nonroad SI >25hp [c]	1,370	0.2%	0.1%	2,297	0.6%	0.1%	2,687	0.7%	0.1%
Recreational SI [c]	4,632	0.8%	0.2%	5,557	1.6%	0.3%	5,912	1.6%	0.3%
Commercial Marine Diesel	36,367	6.5%	1.6%	41,365	11.8%	2.0%	45,411	12.0%	2.1%
Commercial Marine SI	1,370	0.2%	0.1%	1,326	0.4%	0.1%	1,427	0.4%	0.1%
Locomotive	20,937	3.7%	1.0%	16,727	4.8%	0.8%	15,670	4.1%	0.7%
Aircraft	27,891	5.0%	1.3%	30,024	8.6%	1.5%	30,606	8.1%	1.4%
Total Nonroad	328,841	59%	15%	278,561	79%	14%	303,856	80%	14%
Total Highway	230,684	41%	10%	72,377	21%	4%	75,825	20%	3%
Total Mobile Sources	559,525	100%	25%	350,938	100%	17%	379,681	100%	17%
Stationary Point and Area Sources	1,653,392	—	75%	1,712,004	—	83%	1,824,609	—	83%
Total Man-Made Sources	2,212,917	—		2,062,942	—		2,204,290	—	
Mobile Source Percent of Total	25%	—		17%	—		17%	—	25%

[a] These are 48-state inventories. They do not include Alaska and Hawaii.
[b] Excludes natural and miscellaneous sources.
[c] These inventories do not account for the final rule to control emissions from nonroad large spark-ignition engines, recreational marine diesel engines >50 hp, and recreational vehicles, published November 8, 2002.

Table 3.2-3
Annual NO_x Baseline Emission Levels for Mobile and Other Source Categories [a]

Category	1996			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Land-Based Nonroad Diesel	1,583,664	12.1%	6.4%	1,140,727	20.8%	7.3%	1,231,995	23.6%	7.9%
Recreational Marine Diesel ≤50 hp	523	0.0%	0.0%	682	0.0%	0.0%	706	0.0%	0.0%
Recreational Marine Diesel >50 hp [b]	18,917	0.1%	0.1%	34,136	0.6%	0.2%	40,544	0.8%	0.3%
Recreational Marine SI	33,304	0.3%	0.1%	61,749	1.1%	0.4%	67,893	1.3%	0.4%
Nonroad SI ≤25 hp	63,584	0.5%	0.3%	100,119	1.8%	0.6%	116,514	2.2%	0.7%
Nonroad SI >25hp [b]	281,068	2.1%	1.1%	484,504	8.8%	3.1%	567,696	10.9%	3.7%
Recreational SI [b]	8,606	0.1%	0.0%	13,065	0.2%	0.1%	13,539	0.3%	0.1%
Commercial Marine Diesel	959,704	7.3%	3.9%	819,201	14.9%	5.3%	814,827	15.6%	5.2%
Commercial Marine SI	6,428	0.0%	0.0%	4,551	0.1%	0.0%	4,355	0.1%	0.0%
Locomotive	921,556	7.0%	3.8%	612,722	11.2%	3.9%	534,520	10.2%	3.4%
Aircraft	165,018	1.3%	0.7%	228,851	4.2%	1.5%	258,102	4.9%	1.7%
Total Nonroad	4,042,371	31%	17%	3,500,307	64%	22%	3,650,691	70%	24%
Total Highway	9,066,489	69%	37%	1,984,611	36%	13%	1,577,788	30%	10%
Total Mobile Sources	13,108,860	100%	53%	5,484,917	100%	35%	5,228,479	100%	34%
Stationary Point and Area Sources	11,449,752	—	47%	10,050,213	—	65%	10,320,361	—	66%
Total Man-Made Sources	24,558,612	—		15,535,130	—		15,548,840	—	
Mobile Source Percent of Total	53%	—		35%	—		34%	—	

[a] These are 48-state inventories. They do not include Alaska and Hawaii.

[b] These inventories do not account for the final rule to control emissions from nonroad large spark-ignition engines, recreational marine diesel engines >50 hp, and recreational vehicles, published November 8, 2002.

Table 3.2-4
Annual SO_2 Baseline Emission Levels for Mobile and Other Source Categories [a]

Category	1996			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Land-Based Nonroad Diesel	147,926	19.9%	0.8%	252,089	41.7%	1.7%	297,573	43.7%	1.9%
Recreational Marine Diesel ≤50 hp	57	0.0%	0.0%	100	0.0%	0.0%	119	0.0%	0.0%
Recreational Marine Diesel >50 hp	2,194	0.3%	0.0%	3,803	0.6%	0.0%	4,517	0.7%	0.0%
Recreational Marine SI	2,170	0.3%	0.0%	2,522	0.4%	0.0%	2,698	0.4%	0.0%
Nonroad SI ≤25 hp	6,530	0.9%	0.0%	8,347	1.4%	0.1%	9,714	1.4%	0.1%
Nonroad SI >25hp	882	0.1%	0.0%	1,060	0.2%	0.0%	1,211	0.2%	0.0%
Recreational SI	1,673	0.2%	0.0%	2,679	0.4%	0.0%	2,774	0.4%	0.0%
Commercial Marine Diesel	25,948	3.5%	0.1%	32,117	5.3%	0.2%	36,068	5.3%	0.2%
Commercial Marine SI	191,813	25.8%	1.0%	196,918	32.6%	1.3%	210,060	30.8%	1.4%
Locomotive	50,534	6.8%	0.3%	53,832	8.9%	0.4%	58,832	8.6%	0.4%
Aircraft	11,305	1.5%	0.1%	15,267	2.5%	0.1%	16,813	2.5%	0.1%
Total Nonroad	441,032	59%	2%	568,734	94%	4%	640,379	94%	4%
Total Highway	302,938	41%	2%	35,311	6%	0%	40,788	6%	0%
Total Mobile Sources	743,970	100%	4%	604,045	100%	4%	681,167	100%	4%
Stationary Point and Area Sources	17,636,602	—	96%	14,510,426	—	96%	14,782,220	—	96%
Total Man-Made Sources	18,380,572	—		15,114,471	—		15,463,387	—	
Mobile Source Percent of Total	4%	—		4%	—		4%	—	

[a] These are 48-state inventories. They do not include Alaska and Hawaii.

Table 3.2-5
Annual VOC Baseline Emission Levels for Mobile and Other Source Categories [a]

Category	1996			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Land-Based Nonroad Diesel	221,403	2.7%	1.2%	96,855	2.3%	0.7%	97,348	2.1%	0.6%
Recreational Marine Diesel ≤50 hp	128	0.0%	0.0%	108	0.0%	0.0%	80	0.0%	0.0%
Recreational Marine Diesel >50 hp [b]	676	0.0%	0.0%	1,219	0.0%	0.0%	1,448	0.0%	0.0%
Recreational Marine SI	804,488	9.6%	4.3%	380,891	8.9%	2.7%	372,970	8.0%	2.4%
Nonroad SI ≤25 hp	1,330,229	15.9%	7.2%	650,158	15.3%	4.7%	751,883	16.1%	4.9%
Nonroad SI >25hp [b]	44,926	0.5%	0.2%	42,504	1.0%	0.3%	47,411	1.0%	0.3%
Recreational SI [b]	403,984	4.8%	2.2%	719,031	16.9%	5.2%	749,134	16.1%	4.9%
Commercial Marine Diesel	31,545	0.4%	0.2%	37,290	0.9%	0.3%	41,354	0.9%	0.3%
Commercial Marine SI	960	0.0%	0.0%	998	0.0%	0.0%	1,079	0.0%	0.0%
Locomotive	48,381	0.6%	0.3%	36,546	0.9%	0.3%	31,644	0.7%	0.2%
Aircraft	176,394	2.1%	0.9%	239,654	5.6%	1.7%	265,561	5.7%	1.7%
Total Nonroad	3,063,114	37%	17%	2,205,255	52%	16%	2,359,912	51%	15%
Total Highway	5,286,948	63%	28%	2,055,843	48%	15%	2,296,972	49%	15%
Total Mobile Sources	8,350,062	100%	45%	4,261,098	100%	31%	4,656,884	100%	30%
Stationary Point and Area Sources	10,249,136	—	55%	9,648,376	—	69%	10,751,134	—	70%
Total Man-Made Sources	18,599,198	—		13,909,474	—		15,408,018	—	
Mobile Source Percent of Total	45%	—		31%	—		30%	—	

[a] These are 48-state inventories. They do not include Alaska and Hawaii.
[b] These inventories do not account for the final rule to control emissions from nonroad large spark-ignition engines, recreational marine diesel engines >50 hp, and recreational vehicles, published November 8, 2002.

Table 3.2-6
Annual CO Baseline Emission Levels for Mobile and Other Source Categories [a]

Category	1996			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile sources	% of total	short tons	% of mobile source	% of total
Land-Based Nonroad Diesel	1,010,518	1.3%	1.1%	700,017	0.8%	0.7%	793,923	0.8%	0.7%
Recreational Marine Diesel ≤50 hp	365	0.0%	0.0%	395	0.0%	0.0%	356	0.0%	0.0%
Recreational Marine Diesel >50 hp [b]	2,850	0.0%	0.0%	5,143	0.0%	0.0%	6,109	0.0%	0.0%
Recreational Marine SI	1,995,907	2.5%	2.1%	1,977,403	2.4%	2.0%	2,075,666	2.2%	1.9%
Nonroad SI ≤25 hp	16,735,812	21.3%	17.7%	24,675,763	29.8%	25.0%	28,728,492	30.2%	25.8%
Nonroad SI >25hp [b]	2,144,654	2.7%	2.3%	2,785,383	3.4%	2.8%	3,198,141	3.4%	2.9%
Recreational SI [b]	1,824,753	2.3%	1.9%	2,765,874	3.3%	2.8%	2,891,759	3.0%	2.6%
Commercial Marine Diesel	126,382	0.2%	0.1%	159,900	0.2%	0.2%	176,533	0.2%	0.2%
Commercial Marine SI	6,010	0.0%	0.0%	6,702	0.0%	0.0%	7,233	0.0%	0.0%
Locomotive	112,171	0.1%	0.1%	119,302	0.1%	0.1%	119,302	0.1%	0.1%
Aircraft	949,313	1.2%	1.0%	1,387,178	1.7%	1.4%	1,502,265	1.6%	1.3%
Total Nonroad	24,908,737	32%	26%	34,583,061	42%	35%	39,499,779	42%	35%
Total Highway	53,585,364	68%	56%	48,333,986	58%	49%	55,609,767	58%	50%
Total Mobile Sources	78,494,101	100%	83%	82,917,047	100%	84%	95,109,546	100%	85%
Stationary Point and Area Sources	16,318,451	—	17%	15,648,555	—	16%	16,325,306	—	15%
Total Man-Made Sources	94,812,552	—		98,565,602	—		111,434,852	—	
Mobile Source Percent of Total	83%	—		84%	—		85%	—	

[a] These are 48-state inventories. They do not include Alaska and Hawaii.

[b] These inventories do not account for the final rule to control emissions from nonroad large spark-ignition engines, recreational marine diesel engines >50 hp, and recreational vehicles, published November 8, 2002.

3.3 Contribution of Nonroad Diesel Engines to Selected Local Emission Inventories

The contribution of land-based nonroad compression-ignition (CI) engines to $PM_{2.5}$ and NO_x emission inventories in many U.S. cities can be significantly greater than that reflected by national average values.[A] This is not surprising given the high density of these engines one would expect to be operating in urban areas. The EPA selected a collection of typical cities spread across the United States in order to compare projected urban inventories with national average ones for 1996, 2020, and 2030. The results of this analysis are shown below.

3.3.1 $PM_{2.5}$ Emissions

As illustrated in Tables 3.3-1, 3.3-2, and 3.3-3, EPA's city-specific analysis of selected metropolitan areas for 1996, 2020, and 2030 show that land-based nonroad diesel engine engines are a significant contributor to total $PM_{2.5}$ emissions from all man-made sources.

[A] Construction, industrial, and commercial nonroad diesel equipment comprise most of the land-based nonroad emissions inventory. These types of equipment are more concentrated in urban areas where construction projects, manufacturing, and commercial operations are prevalent.

Table 3.3-1
Land-Based Nonroad Percent Contribution
to $PM_{2.5}$ Inventories in Selected Urban Areas in 1996[a]

MSA, CMSA / State	Land-Based Diesel (short tons)	Mobile Sources (short tons)	Total Man-Made Sources (short tons)	Land-Based Diesel as % of Total	Land-Based Diesel as % of Mobile Sources
Atlanta, GA	1,650	7,308	22,190	7%	23%
Boston, MA	4,265	9,539	23,254	18%	45%
Chicago, IL	3,374	10,106	40,339	8%	33%
Dallas-Fort Worth, TX	1,826	5,606	13,667	13%	33%
Indianapolis, IN	1,040	3,126	7,083	15%	33%
Minneapolis, MN	1,484	4,238	15,499	10%	35%
New York, NY	2,991	6,757	23,380	13%	44%
Orlando, FL	764	2,559	5,436	14%	30%
Sacramento, CA	529	2,140	7,103	7%	25%
San Diego, CA	879	3,715	9,631	9%	24%
Denver, CO	1,125	3,199	10,107	11%	35%
El Paso, TX	252	822	1,637	15%	31%
Las Vegas, NV-AZ	1,155	2,700	7,511	15%	43%
Phoenix-Mesa, AZ	1,549	4,994	10,100	15%	31%
Seattle, WA	1,119	4,259	15,187	7%	26%

[a] Includes only direct exhaust emissions; see Chapter 2 for a discussion of secondary fine PM levels.

Table 3.3-2
Annual Land-Based Nonroad Diesel Contributions
to $PM_{2.5}$ Inventories in Selected Urban Areas in 2020[a]

MSA, CMSA / State	Land-Based Diesel (short tons)	Mobile Sources (short tons)	Total Man-Made Sources (short tons)	Land-Based Diesel as % of Total	Land-Based Diesel as % of Mobile Sources
Atlanta, GA	1,429	4,506	22,846	6%	32%
Boston, MA	3,580	6,720	20,365	18%	53%
Chicago, IL	2,824	6,984	42,211	7%	40%
Dallas-Fort Worth, TX	1,499	3,544	15,202	10%	42%
Indianapolis, IN	794	1,779	6,238	13%	45%
Minneapolis, MN	1,188	2,509	15,096	8%	47%
New York, NY	2,573	4,549	21,566	12%	57%
Orlando, FL	652	1,743	5,627	12%	37%
Sacramento, CA	391	1,301	5,505	7%	30%
San Diego, CA	678	2,478	9,135	7%	27%
Denver, CO	923	2,149	10,954	8%	43%
El Paso, TX	212	478	1,140	19%	44%
Las Vegas, NV-AZ	961	2,080	7,804	12%	46%
Phoenix-Mesa, AZ	1,299	3,512	10,768	12%	37%
Seattle, WA	946	3,043	13,094	7%	31%

[a] Includes only direct exhaust emissions; see Chapter 2 for a discussion of secondary fine PM levels.

Table 3.3-3
Land-Based Nonroad Percent Contribution
to $PM_{2.5}$ Inventories in Selected Urban Areas in 2030[a]

MSA, CMSA / State	Land-Based Diesel (short tons)	Mobile Sources (short tons)	Total Man-Made Sources (short tons)	Land-Based Diesel as % of Total	Land-Based Diesel as % of Mobile Sources
Atlanta, GA	1,647	4,937	24,880	7%	33%
Boston, MA	4,132	7,529	21,846	19%	55%
Chicago, IL	3,236	7,735	45,975	7%	42%
Dallas-Fort Worth, TX	1,721	3,919	16,622	10%	44%
Indianapolis, IN	902	1,934	6,753	13%	47%
Minneapolis, MN	1,354	2,769	16,586	8%	49%
New York, NY	2,953	5,064	22,891	13%	58%
Orlando, FL	752	1,957	6,084	12%	38%
Sacramento, CA	447	1,445	5,890	8%	31%
San Diego, CA	777	2,770	10,096	8%	28%
Denver, CO	1,060	2,379	12,117	9%	45%
El Paso, TX	244	524	1,243	20%	47%
Las Vegas, NV-AZ	1,113	2,307	8,512	13%	48%
Phoenix-Mesa, AZ	1,499	3,870	11,989	13%	39%
Seattle, WA	1,084	3,357	14,148	8%	32%

[a] Includes only direct exhaust emissions; see Chapter 2 for a discussion of secondary fine PM levels.

3.3.2 NO_x Emissions

As presented in Tables 3.3-4, 3.3-5, and 3.3-6, EPA’s city-specific analysis of selected metropolitan areas for 1996, 2020, and 2030 show that land-based nonroad diesel engine engines are a significant contributor to total NO_x emissions from all man-made sources.

Table 3.3-4
Land-Based Nonroad Percent Contribution to NO_x Inventories in Selected Urban Areas in 1996

MSA, CMSA / State	Land-Based Diesel (short tons)	Mobile Sources (short tons)	Total Man-Made Sources (short tons)	Land-Based Diesel as % of Total	Land-Based Diesel as % of Mobile Sources
Atlanta, GA	16,238	205,465	298,361	5%	8%
Boston, MA	43,362	232,444	311,045	14%	19%
Chicago, IL	32,276	296,710	509,853	6%	11%
Dallas-Fort Worth, TX	17,852	152,878	186.824	10%	12%
Indianapolis, IN	9,487	89,291	113,300	8%	11%
Minneapolis, MN	13,843	124,437	224,817	6%	11%
New York, NY	29,543	184,384	262,021	11%	16%
Orlando, FL	7,493	61,667	75,714	10%	12%
Sacramento, CA	5,666	55,144	58,757	10%	10%
San Diego, CA	9,460	99,325	107,024	9%	10%
Denver, CO	11,080	86,329	146,807	8%	13%
El Paso, TX	2,498	24,382	30,160	8%	10%
Las Vegas, NV-AZ	11,788	50,724	108,875	11%	23%
Phoenix-Mesa, AZ	15,145	115,544	161,606	9%	13%
Seattle, WA	11,227	115,264	133,840	8%	10%

Table 3.3-5
Annual Land-Based Nonroad Diesel Contributions
to NO_x Inventories in Selected Urban Areas in 2020

MSA, CMSA / State	Land-Based Diesel (short tons)	Mobile Sources (short tons)	Total Man-Made Sources (short tons)	Land-Based Diesel as % of Total	Land-Based Diesel as % of Mobile Sources
Atlanta, GA	12,650	69,816	193,456	7%	18%
Boston, MA	31,282	93,308	167,572	19%	34%
Chicago, IL	24,732	123,823	333,945	7%	20%
Dallas-Fort Worth, TX	13,334	60,745	101,453	13%	22%
Indianapolis, IN	6,982	36,283	60,059	12%	19%
Minneapolis, MN	10,376	47,375	165,775	6%	22%
New York, NY	22,456	67,083	112,960	20%	33%
Orlando, FL	5,837	28,653	45,362	13%	20%
Sacramento, CA	4,297	18,870	23,111	19%	23%
San Diego, CA	7,464	46,005	51,909	14%	16%
Denver, CO	8,251	38,435	103,533	8%	21%
El Paso, TX	1,847	10,105	12,452	15%	18%
Las Vegas, NV-AZ	8,501	26,840	72,829	12%	32%
Phoenix-Mesa, AZ	11,560	48,348	105,185	11%	24%
Seattle, WA	8,283	51,252	76,161	11%	16%

Table 3.3-6
Land-Based Nonroad Percent Contribution
to NO_x Inventories in Selected Urban Areas in 2030

MSA, CMSA / State	Land-Based Diesel (short tons)	Mobile Sources (short tons)	Total Man-Made Sources (short tons)	Land-Based Diesel as % of Total	Land-Based Diesel as % of Mobile Sources
Atlanta, GA	14,190	65,746	191,932	7%	22%
Boston, MA	35,039	92,537	168,422	21%	38%
Chicago, IL	27,525	120,694	334,334	8%	23%
Dallas-Fort Worth, TX	14,839	56,907	100,721	15%	26%
Indianapolis, IN	7,641	34,442	58,793	13%	22%
Minneapolis, MN	11,444	45,326	167,154	7%	25%
New York, NY	25,064	67,163	108,215	23%	37%
Orlando, FL	6,551	28,365	45,267	14%	23%
Sacramento, CA	4,806	17,498	21,952	22%	27%
San Diego, CA	8,401	43,930	50,296	17%	19%
Denver, CO	9,185	37,105	104,217	9%	25%
El Paso, TX	2,062	9,422	11,905	17%	22%
Las Vegas, NV-AZ	9,544	26,349	72,926	13%	36%
Phoenix-Mesa, AZ	12,952	46,280	106,061	12%	28%
Seattle, WA	9,247	49,258	77,133	12%	19%

3.4 Nonroad Diesel Controlled Emissions Inventory Development

This section describes how the controlled emissions inventories were developed for the four categories of nonroad diesel engines affected by this proposal: land-based diesel engines, commercial marine diesel vessels, locomotives, and recreational marine diesel engines. For land-based diesel engines, there are separate sections for criteria (i.e., $PM_{2.5}$, NO_x, SO_2, VOC, and CO) and air toxics emissions development.

3.4.1 Land-Based Diesel Engines—$PM_{2.5}$, NO_x, SO_2, VOC, and CO Emissions

The emission inventory estimates used in this proposed rule were generated using the draft NONROAD2002 model with certain input modifications to account for the in-use diesel fuel sulfur reductions and the additional controls being proposed for the Tier 4 engines. This section will only describe these modifications to the model inputs, since the other aspects of the model, including inputs for earlier engines, are covered in detail in the technical reports that document the draft NONROAD2002 model.

3.4.1.1 Standards and Zero-Hour Emission Factors

The proposed standards that are presented in Section 3 of the preamble are shown in Table 3.4-1. The modeled emission factors corresponding to the proposed standards are shown in Table 3.4-2. These emission factors are derived from the standards by applying an assumed 8% compliance margin to the standard. This compliance margin was derived from data for highway diesel vehicles and used in the HD07 rule. Additionally, a transient adjustment factor is applied, as described below, if the engine power and model year place it in a category subject to a steady-state certification test cycle instead of a transient test.

Besides exhaust emissions, the proposed rule includes changes in crankcase hydrocarbon emissions. Crankcase losses prior to Tier 4 have been modeled as 2.0 percent of exhaust HC, and any crankcase emissions of other pollutants have been considered negligible. For all Tier 4 engines, including those using transitional controls without particulate traps, our modeling now assumes zero crankcase emissions.

3.4.1.2 Transient Adjustment Factors

As shown in Table 3.4-2, the proposed new standards for engines over 75 hp beginning in 2011 or 2012, and for those under 75 hp beginning in 2008, call for use of a transient certification test cycle. Thus, there was no Transient Adjustment Factor (TAF) applied to the emission factors for these engines (i.e., the model applies a TAF of 1.0); the zero-hour emission factor was modeled simply as the value of the standard minus an assumed 8% compliance margin.

Table 3.4-1
Proposed Tier 4 Exhaust Emissions Certification Standards

Engine Power	Emissions Standard (g/bhp-hr)[a]					Model Year
	transitional or final	PM	NO_x	NMHC	CO	
kW < 19 (hp <25)	final	0.30	5.6[b,c]		4.9	2008
19 ≤ kW < 56 (25 ≤ hp < 75)	transitional[d]	0.22	5.6/3.5[b,c]		3.7	2008
	final	0.02	3.5[b]		3.7 [c]	2013
56 ≤ kW < 130 (75 ≤ hp < 175)	transitional	0.01 (100%)	0.30 (50%)	0.14 (50%)	3.7 [c]	2012-2013
	final	0.01 (100%)	0.30 (100%)	0.14 (100%)	3.7 [c]	2014
130 ≤ kW < 560 (175 ≤ hp < 750)	transitional	0.01 (100%)	0.30 (50%)	0.14 (50%)	2.6 [c]	2011-2013
	final	0.01 (100%)	0.30 (100%)	0.14 (100%)	2.6 [c]	2014
kW ≥ 560 (hp ≥ 750)	transitional	0.01 (50%)	0.30 (50%)	0.14 (50%)	2.6 [c]	2011-2013
	final	0.01 (100%)	0.30 (100%)	0.14 (100%)	2.6 [c]	2014

[a] Percentages are model year sales fractions required to comply with the indicated standard.

[b] This is a combined NMHC + NO_x standard.

[c] This emissions standard level is unchanged from the level that applies in the previous model year. For 25-75 hp engines, the transitional NMHC + NO_x standard is 5.6 g/bhp-hr for engines below 50 hp and 3.5 g/bhp-hr for engines at or above 50 hp.

[d] Manufacturers may optionally skip the transitional standards for 25-75 hp engines; the final standards would then take effect for these engines in the 2012 model year.

Table 3.4-2
NONROAD Model EF Inputs for Proposed Tier 4 Exhaust Emissions Standards

Engine Power	Emission Factor Modeling Inputs g/bhp-hr							Model Year
	Type of standard		PM	NO$_x$ [a b]		THC [b,c]	CO [d]	
hp ≤ 11	final [e]		0.28	4.30		0.55	4.11	2008
11 < hp ≤ 25	final [e]		0.28	4.44		0.44	2.16	2008
25 < hp ≤ 50	transitional [f]		0.20	4.73		0.28	1.53	2008
	final		0.018	3.0		0.13	0.15	2013
50 < hp ≤ 75	transitional [f]		0.20	3.0		0.18	2.4	2008
	final		0.018	3.0		0.13	0.24	2013
75 < hp ≤ 100	transitional		0.01	3.0 (50%)	0.28 (50%)	0.13	0.24	2012-2013
	final		0.01	0.28		0.13	0.24	2014
100 < hp ≤ 175	transitional		0.01	2.5 (50%)	0.28 (50%)	0.13	0.87	2012-2013
	final		0.01	0.28		0.13	0.087	2014
175 < hp ≤ 300	transitional		0.01	2.5 (50%)	0.28 (50%)	0.13	7.5	2011-2013
	final		0.01	0.28		0.13	0.075	2014
300 < hp ≤ 600	transitional		0.01	2.5 (50%)	0.28 (50%)	0.13	8.4	2011-2013
	final		0.01	0.28		0.13	0.084	2014
600 < hp ≤ 750	transitional		0.01	2.5 (50%)	0.28 (50%)	0.13	1.3	2011-2013
	final		0.01	0.28		0.13	0.13	2014
hp > 750	trans-itional [g]	50%	0.13	4.1		0.17	0.76	2011-2013
		50%	0.01	0.28		0.13	0.076	
	final		0.01	0.30		0.13	0.076	2014

[a] Percentages are model-year sales fractions required to comply with the indicated standard.

[b] NMHC + NO$_x$ is a combined standard, so for modeling purposes the NO$_x$ and HC are separated using a NO$_x$/HC ratio that approximates the results found in prior test programs, as described in technical report NR-009b.

[c] HC Standards are in terms of NMHC, but the model expects inputs as THC, so a conversion factor of 1.02 is applied to the NMHC value to get the THC model input.

[d] Tier 4 CO is assumed to decrease by 90% from its prior levels in any cases where particulate traps are expected for PM control.

[e] Final standards and emission factor inputs for engines under 25 hp take effect in 2008, starting in 2008 the modeling of these inputs changes to reflect the start of a transient certification test requirement at which time Transient Adjustment Factors are no longer applied to the emission factors.

[f] Transitional standards and emission factor inputs for 25-75 hp engines are based on transient use, so Transient Adjustment Factors will not be applied to the emission factors shown here.

[g] The transitional standards for engines >750 hp consist of 50% engines meeting Tier 2 standards with the 8-mode test and 50% meeting the final Tier 4 standards with transient test. TAFs will only get applied to the emissions of the engines meeting the Tier 2 standards. Application of TAF's is described in technical report NR-009b.[1]

3.4.1.3 Deterioration Rates

The deterioration rates (*d*) used for the modeling of Tier 4 engines are the same as used for Tier 3 engines for all affected pollutants (PM, NO_x, HC, and CO). These are listed in Table 3.4-3 below and are fully documented in technical report NR-009b.[1]

Table 3.4-3
Deterioration Rates for Nonroad Diesel Engines

Pollutant	Relative Deterioration Rate (% increase per %useful life expended)[a]				
	Base/Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
HC	0.047	0.036	0.034	0.027	0.027
CO	0.185	0.101	0.101	0.151	0.151
NO_x	0.024	0.024	0.009	0.008	0.008
PM	0.473	0.473	0.473	0.473	0.473

[a] At the median life point, the Deterioration Factor = 1 + relative deterioration rate.

3.4.1.4 In-Use Sulfur Levels, Certification Sulfur Levels, and Sulfur Conversion Factors

Tables 3.4-4 and 3.4-5 show the certification and in-use fuel sulfur levels by calendar year and engine power range that was assumed for modeling the engines that would be regulated under this rule. The certification sulfur levels are the default fuel sulfur levels used to calculate the zero mile PM and SO_2 emission factors in the model (referred to as S_{base} in Section 3.1.1.2.1). The in-use fuel sulfur level is the episodic fuel sulfur level (referred to as S_{in-use} in Section 3.1.1.2.1). Adjustments to PM and SO_2 for in-use fuel sulfur levels are made relative to the certification sulfur levels in the model. As described above for the baseline inventory development, the in-use fuel sulfur content, fuel consumption, sulfate conversion factor, and exhaust HC emission factor (unburned fuel) determine the SO_2 emissions, and a fraction of the fuel sulfur is also converted to sulfate PM. The changes for modeling of the control case are (a) lower sulfur content for in-use and certification fuel per this proposed rule, and (b) the use of a higher sulfur-to-sulfate conversion factor for engines that are expected to use a particulate trap/filter to achieve the PM standards of 0.01 or 0.02 g/bhp-hr (30% conversion instead of 2.247% that is used for all earlier non-trap equipped engines).

Table 3.4-4
Modeled Certification Diesel Fuel Sulfur Content

Engine Power	Standards	Modeled Certification Fuel Sulfur Content, PPM	Model Year
kW < 56 (hp <75)	Tier 2	2000	through 2007
	transitional	500	2008
	final	15	2013
56 ≤ kW < 75 (75 ≤ hp < 100)	Tier 3 transitional [a]	500	2008-2011
	final	15	2012
75 ≤ kW < 130 (100 ≤ hp < 175)	Tier 3	2000	2007-2011
	final	15	2012
130 ≤ kW < 560 (175 ≤ hp < 750)	Tier 3	2000	2006-2010
	final	15	2011
kW ≥ 560 (hp ≥ 750)	Tier 2	2000	2006-2010
	transitional [b]	50% 2000 50% 15	2011-2013
	final	15	2014

[a] The emission standard here is still Tier 3 as in the Baseline case, but since the Tier 3 standard begins in 2008 for 50-100 hp engines it is assumed that this new technology introduction would allow manufacturers to take advantage of the availability of 500 ppm fuel that year.

[b] The engines remaining at the Tier 2 level would be allowed to continue certifying on the same fuel as earlier Tier 2 engines, but those meeting the Tier 4 0.01 PM standard are assumed to certify on 15 ppm fuel.

Table 3.4-5
Modeled 48-State & 50-State In-Use Diesel Fuel Sulfur Content for Controlled Inventories

Applications	Standards	Modeled In-Use Fuel Sulfur Content, ppm	Calendar Year
Land-based, all power ranges	Baseline	2318	through 2005
		2271	2006
	June intro of 500 ppm	1075	2007
	500 ppm standard	245	2008-2009
	June intro of 15 ppm	100	2010
	Final 15 ppm standard	11	2011+
Recreational Marine, Commercial Marine, and Locomotives	Baseline	2396	through 2005
		2352	2006
	June intro of 500 ppm	1114	2007
	Final 500 ppm standard	252	2008-2009
		233	2010+

3.4.1.5 Modeling 50-75 hp and 75-100 hp Within the NONROAD 50-100 hp Bin

The proposed standards call for different treatment of diesel engines above and below 75 hp (56 kW), but the NONROAD model is not currently designed to handle a 75 hp cutpoint within its 50-100 hp bin. Thus, a modeling method was used in which the NONROAD model was run twice for each scenario -- one time applying the 50-75 hp standards to the 50-100 hp bin, and one time applying the 75-100 hp standards to that bin. Then a weighted average of the two sets of emission inventory outputs was calculated, with the weighting based on overall diesel population and horsepower within the 50-100 hp range. The population weighting was essentially 50/50 (half 50-75 hp and half 75-100 hp), but when the average hp of these two power sub-ranges is taken into account, the resulting inventory weighting was 57% for the 75-100 hp outputs and 43% for the 50-75 hp outputs.

The engine population and power data that was used to calculate this weighting was based on detailed sales data from PSR[12] as described in technical report NR-006b, "Nonroad Engine Population Estimates."

3.4.1.6 Controlled Inventory

Tables 3.4-6a and 3.4-6b present the PM_{10}, $PM_{2.5}$, NO_x, SO_2, VOC, and CO controlled emissions for land-based nonroad diesel engines in 1996 and 2000-2040, for the 48-state and 50-state inventories, respectively.

Table 3.4-6a

Controlled (48-State) Emissions for Land-Based Nonroad Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	191,858	176,510	1,583,664	147,926	221,403	1,010,518
2000	175,155	161,143	1,569,903	167,094	200,366	923,887
2001	169,360	155,811	1,556,973	171,957	191,785	886,723
2002	163,684	150,589	1,544,395	176,819	183,584	850,751
2003	157,726	145,108	1,522,881	181,677	176,201	817,858
2004	152,310	140,125	1,503,228	186,532	169,541	790,468
2005	147,050	135,286	1,483,942	191,385	163,193	764,918
2006	142,043	130,680	1,450,762	192,228	156,295	742,184
2007	130,006	119,606	1,414,673	93,229	149,518	724,213
2008	120,783	111,120	1,373,870	21,757	142,282	709,158
2009	117,672	108,258	1,331,368	22,267	135,201	696,085
2010	113,732	104,633	1,290,526	9,297	128,301	684,775
2011	108,633	99,943	1,234,897	1,032	121,298	661,317
2012	101,846	93,698	1,173,275	1,032	114,587	625,141
2013	94,540	86,976	1,114,569	1,027	108,169	580,076
2014	87,051	80,086	1,030,363	1,021	102,315	534,590
2015	79,578	73,211	950,060	1,014	97,013	490,424
2016	72,412	66,619	874,829	1,009	92,325	449,037
2017	65,636	60,385	804,895	1,005	88,273	411,280
2018	59,412	54,659	742,607	1,003	84,706	377,046
2019	53,834	49,527	686,592	1,003	81,526	345,972
2020	48,976	45,057	637,025	1,005	78,822	318,530
2021	44,686	41,111	595,511	1,009	76,555	294,889
2022	40,803	37,539	560,026	1,015	74,606	273,610
2023	37,312	34,327	529,072	1,022	72,984	254,823
2024	34,073	31,347	502,436	1,029	71,635	237,880
2025	31,098	28,610	479,114	1,038	70,520	222,570
2026	28,431	26,156	459,646	1,047	69,626	209,119
2027	26,095	24,008	443,460	1,058	68,961	197,634
2028	24,198	22,262	429,909	1,070	68,470	188,366
2029	22,486	20,687	418,492	1,083	68,103	180,519
2030	20,912	19,239	410,084	1,096	67,861	173,579
2031	19,617	18,048	403,630	1,109	67,795	168,098
2032	18,444	16,968	398,093	1,123	67,826	163,618
2033	17,347	15,959	393,543	1,137	67,919	159,577
2034	16,334	15,027	389,845	1,151	68,080	156,020
2035	15,427	14,193	387,098	1,166	68,309	153,038
2036	14,653	13,481	385,165	1,180	68,617	150,653
2037	13,942	12,827	383,784	1,195	68,967	148,547
2038	13,548	12,464	383,422	1,210	69,432	146,684
2039	13,236	12,177	383,769	1,226	69,944	145,351
2040	12,957	11,921	384,422	1,241	70,495	144,359

Table 3.4-6b
Controlled (50-State) Emissions for Land-Based Nonroad Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	192,750	177,330	1,592,025	148,729	222,517	1,015,773
2000	175,981	161,903	1,578,148	167,999	201,386	928,674
2001	170,165	156,552	1,565,144	172,889	192,765	891,304
2002	164,467	151,310	1,552,490	177,777	184,524	855,132
2003	158,487	145,808	1,530,854	182,662	177,107	822,062
2004	153,045	140,802	1,511,087	187,544	170,414	794,522
2005	147,761	135,940	1,491,692	192,424	164,035	768,838
2006	142,732	131,314	1,458,315	193,272	157,104	745,994
2007	130,636	120,185	1,422,017	93,735	150,293	727,946
2008	121,368	111,658	1,380,984	21,875	143,022	712,836
2009	118,245	108,786	1,338,243	22,388	135,906	699,719
2010	114,290	105,147	1,297,178	9,347	128,973	688,377
2011	109,168	100,435	1,241,223	1,038	121,935	664,805
2012	102,347	94,159	1,179,237	1,038	115,188	628,436
2013	95,004	87,403	1,120,193	1,033	108,735	583,127
2014	87,475	80,477	1,035,489	1,026	102,849	537,388
2015	79,963	73,566	954,717	1,020	97,519	492,974
2016	72,758	66,937	879,052	1,014	92,806	451,351
2017	65,944	60,669	808,721	1,010	88,733	413,376
2018	59,687	54,912	746,089	1,009	85,149	378,949
2019	54,078	49,752	689,768	1,009	81,954	347,705
2020	49,194	45,258	639,935	1,011	79,238	320,115
2021	44,881	41,290	598,209	1,015	76,959	296,347
2022	40,979	37,701	562,551	1,020	75,001	274,958
2023	37,472	34,474	531,454	1,027	73,371	256,081
2024	34,220	31,482	504,702	1,035	72,015	239,060
2025	31,232	28,734	481,283	1,044	70,894	223,684
2026	28,555	26,270	461,742	1,053	69,996	210,176
2027	26,210	24,113	445,499	1,064	69,328	198,641
2028	24,304	22,360	431,900	1,076	68,834	189,329
2029	22,585	20,778	420,447	1,089	68,466	181,441
2030	21,004	19,323	412,011	1,102	68,223	174,465
2031	19,704	18,128	405,538	1,115	68,157	168,958
2032	18,526	17,044	399,987	1,129	68,189	164,459
2033	17,426	16,032	395,428	1,143	68,282	160,400
2034	16,409	15,096	391,724	1,157	68,444	156,827
2035	15,500	14,260	388,976	1,172	68,676	153,833
2036	14,722	13,544	387,045	1,187	68,985	151,436
2037	14,009	12,888	385,668	1,202	69,338	149,320
2038	13,613	12,524	385,312	1,217	69,805	147,450
2039	13,300	12,236	385,667	1,232	70,321	146,113
2040	13,020	11,979	386,330	1,248	70,875	145,119

3.4.2 Land-Based Diesel Engines—Air Toxics Emissions

Since air toxics emissions are part of the VOC emissions inventory, NMHC standards being proposed in this rule would also affect air toxics emissions. Tables 3.4-7a and 3.4-7b show 48-state and 50-state estimated emissions for five major air toxics, benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and acrolein, resulting from the proposed rule. The EPA uses the same fractions used to calculate the base air toxic emissions without the proposed rule (see section 3.1.2), along with the estimated VOC emissions resulting from the proposed rule, to calculate the air toxics emissions resulting from the proposed rule.

Table 3.4-7a
Controlled (48-State) Air Toxic Emissions for Land-Based Nonroad Diesel Engines (short tons)

Year	Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
2000	4,007	23,643	10,619	401	601
2005	3,264	19,257	8,649	326	490
2007	2,990	17,643	7,924	299	449
2010	2,556	15,140	6,800	257	385
2015	1,940	11,448	5,142	194	291
2020	1,576	9,301	4,178	158	236
2025	1,410	8,321	3,738	141	212
2030	1,357	8,008	3,597	136	204

Table 3.4-7b
Controlled (50-State) Air Toxic Emissions for Land-Based Nonroad Diesel Engines (short tons)

Year	Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
2000	4,028	23,764	10,673	403	604
2005	3,281	19,356	8,694	328	492
2007	3,006	17,735	7,966	301	451
2010	2,579	15,219	6,836	258	387
2015	1,950	11,507	5,168	195	293
2020	1,585	9,350	4,200	158	238
2025	1,418	8,366	3,757	142	213
2030	1,364	8,050	3,616	136	205

3.4.3 Commercial Marine Vessels and Locomotives

The control case locomotive and commercial marine inventories for VOC, CO, and NO_x are identical to the base case inventories, since no new controls are being proposed for these engines. However, due to the diesel fuel sulfur changes that are being proposed, decreases are expected in PM and SO_2 inventories for these engines.

The method used for estimating PM and SO_2 emissions in the control case is essentially the same as described in Section 3.1.3 for the base case, but the fuel sulfur levels in the equations are changed to reflect the control case sulfur. The control case PM and SO_2 emission inventory estimates presented here assume that locomotive and commercial marine applications would use diesel fuel meeting a 500 ppm sulfur standard beginning in June 2007. This was modeled as 340 ppm sulfur outside of California and 120 ppm in California, based on available fuel survey data for in-use highway fuel relative to the existing 500 ppm highway diesel fuel sulfur standards. Additional sulfur adjustments were made to account for the "spillover" of low sulfur highway fuel meeting a 15 ppm standard in the applicable years prior to the start of the proposed 15 ppm nonroad fuel standard.

As in the base case, the same sulfur-to-sulfate conversion rate was used as for land-based diesel applications prior to their use of aftertreatment (2.247%). The fuel sulfur levels were calculated as weighted average in-use levels of (a) uncontrolled nonroad diesel fuel at 3400 ppm sulfur, (b) controlled locomotive and marine diesel fuel at 340 ppm, (c) "spillover" of low sulfur highway diesel fuel into use by nonroad applications outside of California, and (d) full use of low sulfur California fuel in all nonroad applications in California. The slight decrease in average sulfur level in 2006 is due to the introduction of highway diesel fuel meeting the 2007 15 ppm standard, and the "spillover" of this highway fuel into the nonroad fuel pool. Note that there are transition years in which the control sulfur level begins in June, in which case the annual average sulfur level shown reflects an interpolation of 5 months at the higher sulfur level of the prior year plus 7 months at the new lower sulfur level. The derivation of these sulfur levels are described in more detail in Chapter 7.

The control case locomotive and commercial marine PM inventories were calculated by subtracting the sulfate PM benefits (from decreased fuel sulfur content) described above from the base case locomotive and commercial marine PM inventories. The 48-state and 50-state control case locomotive and commercial marine $PM_{2.5}$ and SO_2 inventories are given in Tables 3.4-8a and 3.4-8b, respectively.

Table 3.4-8a
Controlled (48-State) Fuel Sulfur Levels, SO_2,
Sulfate PM, and $PM_{2.5}$ Emissions for Locomotives and Commercial Marine Vessels

Year	Control Sulfur Level (ppm)	Control					
		SO_2		Sulfate PM		Total $PM_{2.5}$	
		Loco (tons/yr)	CMV (tons/yr)	Loco (tons/yr)	CMV (tons/yr)	Loco (tons/yr)	CMV (tons/yr)
2007	1114	24,051	13,446	1,935	1,082	17,612	37,523
2008	252	5,457	3,071	439	247	15,673	36,944
2009	252	5,495	3,105	442	250	15,462	37,136
2010	233	5,119	2,904	412	234	14,932	37,310
2011	233	5,205	2,936	419	236	15,186	37,502
2012	233	5,230	2,969	421	239	14,927	37,693
2013	233	5,245	3,002	422	242	14,639	37,885
2014	233	5,260	3,036	423	244	14,350	38,077
2015	233	5,285	3,071	425	247	14,083	38,269
2016	233	5,339	3,106	430	250	13,893	38,460
2017	233	5,370	3,141	432	253	13,636	38,652
2018	233	5,399	3,177	434	256	13,707	38,844
2019	233	5,430	3,214	437	259	13,444	39,036
2020	233	5,449	3,251	438	262	13,147	39,228
2021	233	5,498	3,288	442	265	12,920	39,606
2022	233	5,547	3,326	446	268	12,687	39,985
2023	233	5,597	3,365	450	271	12,801	40,363
2024	233	5,647	3,404	454	274	12,561	40,741
2025	233	5,698	3,444	458	277	12,316	41,119
2026	233	5,749	3,485	463	280	12,066	41,498
2027	233	5,801	3,526	467	284	12,174	41,876
2028	233	5,853	3,567	471	287	11,916	42,255
2029	233	5,905	3,610	475	290	11,652	42,633
2030	233	5,959	3,653	479	294	11,756	43,012
2031	233	6,012	3,697	484	297	11,485	43,390
2032	233	6,065	3,741	488	301	11,208	43,769
2033	233	6,119	3,786	492	305	11,308	44,148
2034	233	6,174	3,832	497	308	11,022	44,527
2035	233	6,229	3,878	501	312	11,120	44,905
2036	233	6,285	3,926	506	316	11,219	45,284
2037	233	6,341	3,974	510	320	10,923	45,663
2038	233	6,397	4,023	515	324	11,020	46,042
2039	233	6,454	4,072	519	328	10,714	46,421
2040	233	6,512	4,123	524	332	10,810	46,801

Table 3.4-8b
Controlled (50-State) Fuel Sulfur Levels, $SO_{2,}$
Sulfate PM, and $PM_{2.5}$ Emissions for Locomotives and Commercial Marine Vessels

Year	Control Sulfur Level (ppm)	Control					
		SO_2		Sulfate PM		Total $PM_{2.5}$	
		Loco (tons/yr)	CMV (tons/yr)	Loco (tons/yr)	CMV (tons/yr)	Loco (tons/yr)	CMV (tons/yr)
2007	1114	24,084	14,145	1,938	1,138	17,637	39,473
2008	252	5,465	3,231	440	260	15,695	38,864
2009	252	5,503	3,267	443	263	15,484	39,066
2010	233	5,126	3,055	412	246	14,952	39,249
2011	233	5,213	3,088	419	248	15,207	39,451
2012	233	5,237	3,123	421	251	14,947	39,653
2013	233	5,252	3,158	423	254	14,659	39,854
2014	233	5,268	3,194	424	257	14,369	40,056
2015	233	5,292	3,231	426	260	14,103	40,258
2016	233	5,347	3,267	430	263	13,912	40,460
2017	233	5,378	3,304	433	266	13,655	40,662
2018	233	5,407	3,342	435	269	13,726	40,863
2019	233	5,438	3,381	437	272	13,462	41,065
2020	233	5,456	3,420	439	275	13,165	41,267
2021	233	5,505	3,459	443	278	12,938	41,665
2022	233	5,555	3,499	447	282	12,705	42,063
2023	233	5,605	3,540	451	285	12,818	42,461
2024	233	5,655	3,581	455	288	12,579	42,859
2025	233	5,706	3,623	459	291	12,333	43,257
2026	233	5,757	3,666	463	295	12,083	43,655
2027	233	5,809	3,709	467	298	12,191	44,053
2028	233	5,861	3,753	472	302	11,932	44,451
2029	233	5,914	3,798	476	306	11,669	44,849
2030	233	5,967	3,843	480	309	11,773	45,248
2031	233	6,020	3,889	484	313	11,501	45,646
2032	233	6,074	3,935	489	317	11,223	46,044
2033	233	6,128	3,983	493	320	11,323	46,443
2034	233	6,183	4,031	497	324	11,037	46,841
2035	233	6,238	4,080	502	328	11,136	47,240
2036	233	6,293	4,130	506	332	11,235	47,638
2037	233	6,350	4,180	511	336	10,938	48,037
2038	233	6,406	4,232	515	340	11,035	48,436
2039	233	6,463	4,284	520	345	10,729	48,834
2040	233	6,521	4,337	525	349	10,825	49,233

3.4.4 Recreational Marine Engines

Even though this proposed rule does not include any emission standards for marine engines, there are PM and SO_2 benefits associated with these engines due to the proposed fuel sulfur standards. The emission inventory estimates presented in Tables 3.4-9a and 3.4-9b assume that recreational marine applications would use diesel fuel meeting the same standards as locomotive and commercial marine diesel fuel, which means an in-use sulfur content of 1114 ppm in the 2007 transition year and 232 ppm in 2010 and later as shown in Table 3.4-5. Consistent with the baseline inventory described above, these inventory values do not include the benefits associated with the standards promulgated in September 2002 for diesel recreational marine engines.

Table 3.4-9a
Controlled (48-State) Emissions for Recreational Marine Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	529	487	19,440	2,251	803	3,215
2000	594	547	21,899	2,537	900	3,613
2001	611	562	22,548	2,613	923	3,713
2002	627	577	23,196	2,689	947	3,814
2003	643	592	23,844	2,765	970	3,913
2004	660	607	24,492	2,841	992	4,013
2005	676	622	25,139	2,917	1,015	4,112
2006	688	633	25,790	2,939	1,037	4,211
2007	576	530	26,439	1,428	1,059	4,309
2008	497	457	27,088	331	1,081	4,406
2009	507	467	27,736	339	1,102	4,503
2010	516	474	28,384	321	1,124	4,599
2011	526	484	29,028	328	1,145	4,695
2012	535	493	29,671	336	1,166	4,790
2013	545	502	30,314	343	1,186	4,884
2014	555	511	30,957	351	1,207	4,979
2015	565	520	31,600	358	1,227	5,072
2016	574	528	32,244	365	1,247	5,166
2017	584	537	32,888	373	1,268	5,260
2018	593	546	33,531	380	1,288	5,353
2019	603	555	34,174	388	1,308	5,445
2020	612	563	34,817	395	1,328	5,538
2021	621	572	35,460	402	1,347	5,630
2022	631	580	36,103	410	1,367	5,722
2023	640	589	36,746	417	1,387	5,814
2024	649	597	37,388	425	1,406	5,906
2025	658	605	38,031	432	1,426	5,997
2026	667	614	38,673	440	1,446	6,089
2027	677	622	39,316	447	1,465	6,181
2028	686	631	39,959	454	1,486	6,275
2029	696	640	40,604	462	1,507	6,370
2030	706	650	41,250	469	1,528	6,465
2031	716	659	41,896	477	1,550	6,561
2032	726	668	42,543	484	1,571	6,656
2033	736	677	43,189	491	1,592	6,752
2034	746	687	43,836	499	1,614	6,848
2035	757	696	44,483	506	1,636	6,945
2036	767	705	45,131	514	1,658	7,041
2037	777	715	45,779	521	1,680	7,139
2038	788	725	46,428	529	1,703	7,238
2039	798	734	47,076	536	1,725	7,336
2040	809	744	47,725	543	1,748	7,435

Table 3.4-9b
Controlled (50-State) Emissions for Recreational Marine Diesel Engines (short tons)

Year	PM_{10}	$PM_{2.5}$	NO_x	SO_2	VOC	CO
1996	532	490	19,562	2,265	808	3,236
2000	598	550	22,036	2,553	906	3,635
2001	615	566	22,689	2,629	929	3,737
2002	631	581	23,342	2,706	953	3,838
2003	648	596	23,994	2,783	976	3,938
2004	664	611	24,646	2,859	999	4,038
2005	680	626	25,297	2,936	1,021	4,138
2006	692	637	25,952	2,957	1,044	4,237
2007	579	533	26,605	1,437	1,066	4,336
2008	500	460	27,258	333	1,088	4,434
2009	511	470	27,911	341	1,109	4,531
2010	519	477	28,563	323	1,131	4,628
2011	529	487	29,210	330	1,152	4,724
2012	539	496	29,858	338	1,173	4,820
2013	549	505	30,505	345	1,194	4,915
2014	559	514	31,152	353	1,214	5,010
2015	568	523	31,798	360	1,235	5,104
2016	578	532	32,446	368	1,255	5,199
2017	588	541	33,094	375	1,276	5,293
2018	597	549	33,742	383	1,296	5,386
2019	607	558	34,389	390	1,316	5,480
2020	616	567	35,036	398	1,336	5,573
2021	625	575	35,683	405	1,356	5,665
2022	635	584	36,330	412	1,376	5,758
2023	644	592	36,977	420	1,395	5,850
2024	653	601	37,623	427	1,415	5,943
2025	662	609	38,270	435	1,435	6,035
2026	671	618	38,916	442	1,455	6,127
2027	681	626	39,563	450	1,475	6,220
2028	690	635	40,210	457	1,495	6,314
2029	700	644	40,860	465	1,516	6,410
2030	710	654	41,510	472	1,538	6,506
2031	721	663	42,160	480	1,559	6,602
2032	731	672	42,810	487	1,581	6,698
2033	741	682	43,461	495	1,602	6,795
2034	751	691	44,112	502	1,624	6,891
2035	761	700	44,763	509	1,646	6,988
2036	772	710	45,414	517	1,668	7,086
2037	782	720	46,067	524	1,691	7,184
2038	793	729	46,719	532	1,713	7,283
2039	803	739	47,372	539	1,736	7,382
2040	814	749	48,025	547	1,759	7,482

3.5 Anticipated Emission Reductions With the Proposed Rule

Emissions from nonroad diesel engines will continue to be a significant part of the emissions inventory in the coming years. In the absence of new emission standards, we expect overall emissions from nonroad diesel engines to generally decline across the nation for the next

10 to 15 years, depending on the pollutant. Although nonroad diesel engine emissions decline during this period, this trend will not be enough to adequately reduce the large amount of emissions that these engines contribute. In addition, after the 2010 to 2015 time period we project that this trend reverses and emissions rise into the future in the absence of additional regulation of these engines. The initial downward trend occurs as the nonroad fleet becomes increasingly dominated over time by engines that comply with existing emission regulations. The upturn in emissions beginning around 2015 results as growth in the nonroad sector overtakes the effect of the existing emission standards.

The engine and fuel standards in this proposal will affect fine particulate matter ($PM_{2.5}$), oxides of nitrogen (NO_x), sulfur oxides (SO_2), volatile organic hydrocarbons (VOC), air toxics, and carbon monoxide (CO). For engines used in locomotives, commercial marine vessels, and recreational marine vessels, the proposed fuel standards will affect $PM_{2.5}$ and SO_2.

This section discusses the expected emission reductions associated with this proposal. The baseline case represents future emissions with current standards. The controlled case estimates the future emissions of these engines based on the proposed standards and fuel requirements in this notice. Both 48-state and 50-state results are presented. Tables 3.5-1a and 3.5-1b present a summary of the total 48-state and 50-state emission reductions for each pollutant.

3.5.1 $PM_{2.5}$ Reductions

48-State and 50-state emissions of $PM_{2.5}$ from land-based nonroad diesel engines are shown in Tables 3.5-2a and 3.5-2b, respectively, along with estimates of the reductions from this proposal. $PM_{2.5}$ will be reduced due to the proposed PM exhaust emission standards and changes in the sulfur level in nonroad diesel fuel. The exhaust emission standards begin in 2008 for engines less than 75 hp, and are completely phased in for all hp categories by 2014. Nonroad diesel fuel sulfur is reduced to a 500 ppm standard in June of 2007, and further reduced for land-based nonroad diesel engines to a 15 ppm standard (11 ppm in-use) in June of 2010. The 15 ppm standard is fully phased in starting in 2011.

Tables 3.5-2a and 3.5-2b present results for five year increments from 2000 to 2030. Individual years from 2007 to 2011 are also included, since fuel sulfur levels are changing during this period. Emissions are projected to 2030 in order to reflect close to complete turnover of the fleet to engines meeting the proposed standards. For comparison purposes, emissions reductions are also shown from reducing the diesel fuel sulfur level to 500 ppm beginning in June of 2007, without any new emission standards or any additional sulfur level reductions.

Table 3.5-1a
Total Emission Reductions (48-State) from Proposed Rule

Year	PM$_{2.5}$	NO$_x$	SO$_2$	VOC	CO	Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
2000	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0
2007	10,605	0	142,948	0	0	0	0	0	0	0
2008	19,061	301	249,746	29	0	1	3	2	0	0
2009	19,998	619	254,544	59	0	1	7	3	0	0
2010	21,864	1,007	270,977	90	0	2	11	5	0	0
2011	25,496	20,574	285,003	862	14,487	17	102	46	2	3
2015	52,476	217,575	305,639	8,788	182,520	176	1,037	466	18	26
2020	85,254	503,701	331,840	18,033	381,487	361	2,128	956	36	54
2025	109,325	693,857	358,863	24,624	520,864	492	2,906	1,305	49	74
2030	126,910	821,911	385,932	29,487	620,345	590	3,479	1,563	59	88

Table 3.5-1b
Total Emission Reductions (50-State) from Proposed Rule

Year	PM$_{2.5}$	NO$_x$	SO$_2$	VOC	CO	Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
2000	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0
2007	10,705	0	144,298	0	0	0	0	0	0	0
2008	19,238	304	252,100	29	0	1	3	2	0	0
2009	20,181	624	256,935	59	0	1	7	3	0	0
2010	22,058	1,015	273,470	91	0	2	11	5	0	0
2011	25,712	20,717	287,583	868	14,585	17	102	46	2	3
2015	52,851	218,939	308,386	8,841	183,596	177	1,043	469	18	27
2020	85,827	506,815	334,799	18,141	383,730	363	2,141	961	36	54
2025	110,026	698,000	362,041	24,769	523,844	495	2,923	1,313	50	74
2030	127,708	826,690	389,337	29,660	623,851	593	3,500	1,572	59	89

Table 3.5-2a
Estimated National (48-State) PM$_{2.5}$ Emissions and Reductions From Nonroad Land-Based Diesel Engines[a]

Year	$PM_{2.5}$ Emissions [short tons]			$PM_{2.5}$ Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007; No Tier 4 standards	With Rule (Fuel sulfur reduced to 15 ppm in 2010; Tier 4 standards)	With fuel sulfur reduced to 500 ppm in 2007; No Tier 4 standards	With Rule
2000	161,143	161,143	161,143	0	0
2005	135,286	135,286	135,286	0	0
2007	127,089	119,606	119,606	7,483	7,483
2008	124,789	111,657	111,120	13,132	13,669
2009	122,815	109,378	108,258	13,437	14,557
2010	121,007	107,265	104,633	13,742	16,374
2011	119,865	105,816	99,943	14,049	19,922
2015	119,957	104,682	73,211	15,275	46,745
2020	124,344	107,543	45,057	16,801	79,277
2025	131,644	113,335	28,610	18,309	103,034
2030	139,527	119,710	19,239	19,817	120,288

[a] $PM_{2.5}$ represents 92% of PM10 emissions.

Table 3.5-2b
Estimated National (50-State) $PM_{2.5}$
Emissions and Reductions From Nonroad Land-Based Diesel Engines[a]

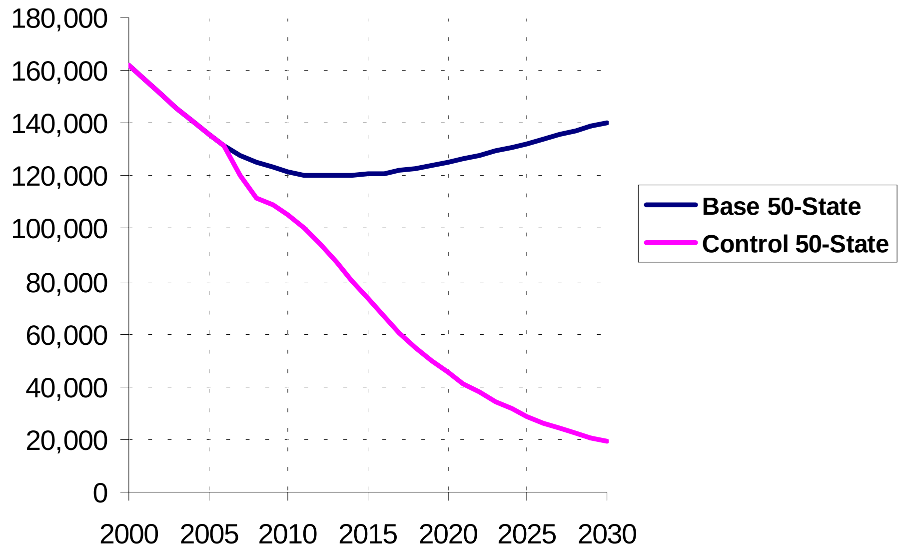
Year	$PM_{2.5}$ Emissions [short tons]			$PM_{2.5}$ Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007; No Tier 4 standards	With Rule (Fuel sulfur reduced to 15 ppm in 2010; Tier 4 standards)	With fuel sulfur reduced to 500 ppm in 2007; No Tier 4 standards	With Rule
2000	161,903	161,903	161,903	0	0
2005	135,940	135,940	135,940	0	0
2007	127,708	120,185	120,185	7,524	7,524
2008	125,401	112,197	111,658	13,204	13,743
2009	123,422	109,911	108,786	13,510	14,636
2010	121,609	107,792	105,147	13,817	16,462
2011	120,466	106,341	100,435	14,125	20,032
2015	120,575	105,218	73,566	15,357	47,010
2020	124,990	108,106	45,258	16,883	79,732
2025	132,345	113,936	28,734	18,409	103,611
2030	140,277	120,352	19,323	19,925	120,954

[a] $PM_{2.5}$ represents 92% of PM10 emissions.

The benefits in the early years of the program (i.e., pre-2010) are primarily from reducing the diesel fuel sulfur level to 500 ppm. As the standards phase in and fleet turnover occurs, $PM_{2.5}$ emissions are impacted more significantly from the proposed rule requirements. $PM_{2.5}$ emissions are reduced roughly 120,000 tons with the proposed rule by 2030.

Figure 3.5-1 shows EPA's estimate of 50-state $PM_{2.5}$ emissions from land-based diesel engines for 2000 to 2030 with and without the proposed $PM_{2.5}$ rule. By 2030, we estimate that $PM_{2.5}$ emissions from this source would be reduced by 86 percent in that year.

Figure 3.5-1: Estimated Reductions in $PM_{2.5}$ Emissions From Land-Based Nonroad Engines (tons/year)



Nonroad diesel engines used in locomotives, commercial marine vessels, and recreational marine vessels are not affected by the emission standards of this proposal. $PM_{2.5}$ emissions from these engines would be reduced by the reductions in diesel fuel sulfur for these types of engines from an in-use average of 2400 ppm today to an in-use average of about 240 ppm in 2010. The estimated 48-state and 50-state reductions in $PM_{2.5}$ emissions from these engines based on the proposed change in diesel fuel sulfur are given in Tables 3.5-3a and 3.5-3b, respectively. Total $PM_{2.5}$ reductions reach roughly 6,700 tons in 2030 for these diesel nonroad engine categories.

Tables 3.5-4a and 3.5-4b present the $PM_{2.5}$ emissions and reductions for all nonroad diesel categories combined. The 50-state results are also presented graphically in Figure 3.5-2. For all nonroad diesel categories combined, the estimated reductions in $PM_{2.5}$ emissions are 85,000 tons in 2020, increasing to 127,000 tons in 2030. Simply reducing the fuel sulfur level to 500 ppm in 2007 would result in $PM_{2.5}$ reductions of 23,000 tons in 2020 and 26,000 tons in 2030.

Table 3.5-3a
Estimated National (48-State) $PM_{2.5}$ Reductions From Locomotives, Commercial Marine, and Recreational Marine Diesel Engines

Year	$PM_{2.5}$ Reductions with Rule [short tons]			
	Locomotives	Commerical Marine Diesel	Recreational Marine Diesel	Total $PM_{2.5}$ Reductions
2000	0	0	0	0
2005	0	0	0	0
2007	1,929	1,078	114	3,121
2008	3,321	1,869	202	5,392
2009	3,345	1,890	206	5,441
2010	3,368	1,911	212	5,491
2011	3,426	1,932	216	5,574
2015	3,476	2,019	235	5,730
2020	3,581	2,137	260	5,978
2025	3,744	2,263	285	6,292
2030	3,914	2,399	308	6,621

Table 3.5-3b
Estimated National (50-State) $PM_{2.5}$ Reductions From Locomotives, Commercial Marine, and Recreational Marine Diesel Engines

Year	$PM_{2.5}$ Reductions with Rule [short tons]			
	Locomotives	Commerical Marine Diesel	Recreational Marine Diesel	Total $PM_{2.5}$ Reductions
2000	0	0	0	0
2005	0	0	0	0
2007	1,931	1,134	115	3,181
2008	3,326	1,966	203	5,495
2009	3,349	1,988	208	5,545
2010	3,373	2,010	213	5,595
2011	3,430	2,032	217	5,680
2015	3,480	2,124	237	5,842
2020	3,586	2,248	262	6,095
2025	3,749	2,380	286	6,415
2030	3,919	2,524	311	6,754

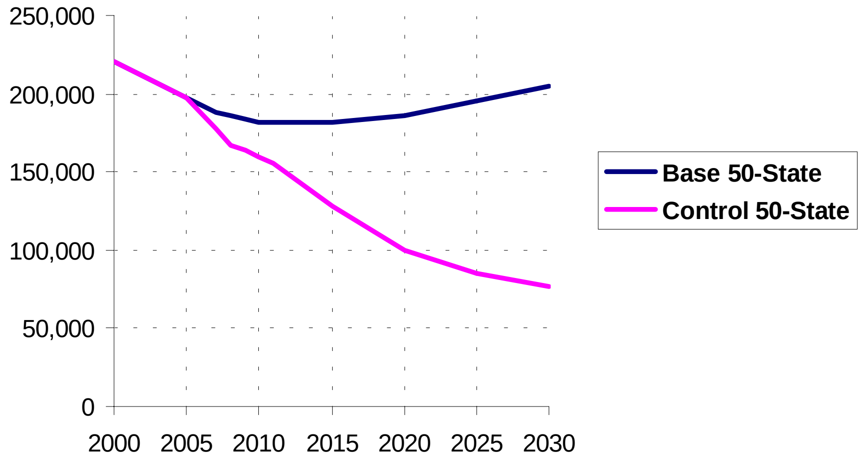
Table 3.5-4a
Estimated National (48-State) $PM_{2.5}$ Emissions and Reductions from
Land-Based Nonroad, Locomotive, Commercial Marine, and Recreational Marine Vessels

Year	$PM_{2.5}$ Emissions [short tons]			$PM_{2.5}$ Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels
2000	218,311	218,311	218,311	0	0
2005	194,554	194,554	194,554	0	0
2007	185,875	175,270	175,270	10,605	10,605
2008	183,256	164,731	164,195	18,525	19,061
2009	181,321	162,443	161,323	18,878	19,998
2010	179,213	159,981	157,349	19,232	21,864
2011	178,610	158,987	153,114	19,622	25,496
2015	178,559	157,554	126,083	21,005	52,476
2020	183,250	160,481	97,996	22,769	85,254
2025	191,976	167,376	82,651	24,600	109,325
2030	201,567	175,128	74,657	26,438	126,910

Table 3.5-4b
Estimated National (50-State) $PM_{2.5}$ Emissions and Reductions from
Land-Based Nonroad, Locomotive, Commercial Marine, and Recreational Marine Vessels

Year	$PM_{2.5}$ Emissions [short tons]			$PM_{2.5}$ Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels
2000	221,035	221,035	221,035	0	0
2005	197,228	197,228	197,228	0	0
2007	188,532	177,828	177,828	10,705	10,705
2008	185,916	167,217	166,678	18,699	19,238
2009	183,986	164,931	163,805	19,055	20,181
2010	181,883	162,471	159,826	19,412	22,058
2011	181,291	161,486	155,579	19,805	25,712
2015	181,301	160,101	128,449	21,199	52,851
2020	186,084	163,105	100,257	22,979	85,827
2025	194,960	170,135	84,933	24,825	110,026
2030	204,705	178,026	76,997	26,679	127,708

Figure 3.5-2: Estimated Reductions in $PM_{2.5}$ Emissions From Land-Based Nonroad Engines, CMVs, RMVs, and Locomotives (tons/year)



3.5.2 NO_x Reductions

Tables 3.5-5a and 3.5-5b show the estimated 48-state and 50-state NO_x emissions in five year increments from 2000 to 2030 with and without the proposed rule and the estimated emissions reductions. The 50-state results are shown graphically in Figure 3.5-3. By 2030, we estimate that NO_x emissions from these engines will be reduced by 67 percent in that year.

NO_x emissions from locomotives, commercial marine diesel vessels, and recreational marine diesel vessels are not affected by this proposal.

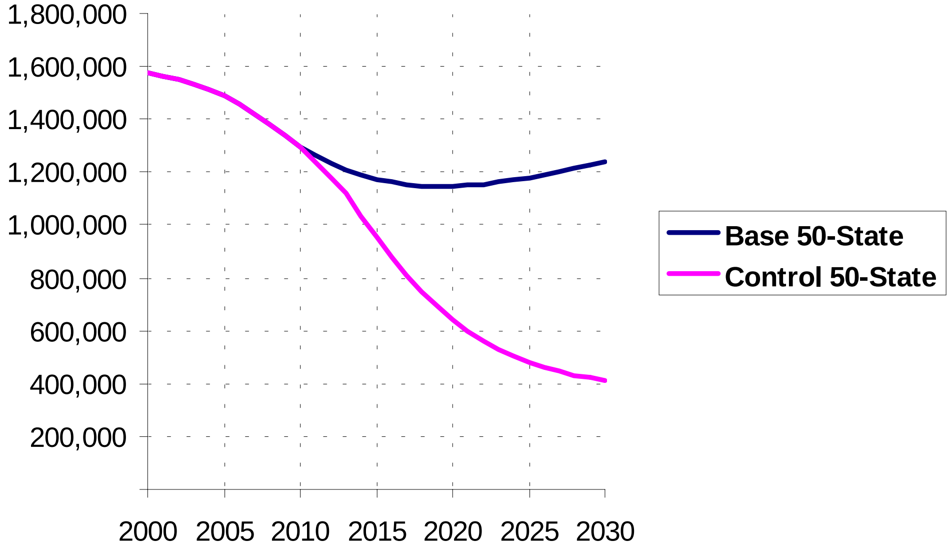
Table 3.5-5a
Estimated National (48-State) NO_x Emissions and Reductions From Nonroad Land-Based Diesel Engines

Year	NO_x Emissions Without Rule [short tons]	NO_x Emissions With Rule	NO_x Reductions With Rule
2000	1,569,903	1,569,903	0
2005	1,483,942	1,483,942	0
2010	1,291,533	1,290,526	1,007
2015	1,167,635	950,060	217,575
2020	1,140,727	637,025	503,701
2030	1,231,995	410,084	821,911

Table 3.5-5b
Estimated National (50-State) NO_x Emissions and Reductions From Nonroad Land-Based Diesel Engines

Year	NO_x Emissions Without Rule [short tons]	NO_x Emissions With Rule	NO_x Reductions With Rule
2000	1,578,148	1,578,148	0
2005	1,491,692	1,491,692	0
2010	1,298,193	1,297,178	1,015
2015	1,173,656	954,717	218,939
2020	1,146,750	639,935	506,815
2030	1,238,701	412,011	826,690

Figure 3.5-3: Estimated Reductions in NOx Emissions From Land-Based Nonroad Engines (tons/year)



3.5.3 SO_2 Reductions

As part of this proposal, sulfur levels in fuel would be significantly reduced, leading to large reductions in nonroad diesel SO_2 emissions. By 2007, the sulfur in diesel fuel used by all nonroad diesel engines would be reduced from the current average in-use level of roughly 2300 ppm to an average in-use level of about 1100 ppm. By 2010, the sulfur in diesel fuel used by land-based nonroad engines would be reduced to an average in-use level of 11 ppm with a maximum level of 15 ppm. The sulfur in diesel fuel used by locomotives, commercial marine, and recreational marine engines would remain at an average in-use level of about 230 ppm.

48-State and 50-state emissions of SO_2 from land-based nonroad diesel engines are shown in Tables 3.5-6a and 3.5-6b, respectively, along with estimates of the reductions from this proposal. Results are presented for five year increments from 2000 to 2030. Individual years from 2007 to 2011 are also included, since fuel sulfur levels are changing during this period. SO_2 will be reduced due to the changes in the sulfur level in nonroad diesel fuel. For comparison purposes, emissions reductions are also shown from reducing the diesel fuel sulfur level to 500 ppm beginning in June of 2007, without any new emission standards or any additional sulfur level reductions.

Table 3.5-6a
Estimated National (48-State) SO_2
Emissions and Reductions From Nonroad Land-Based Diesel Engines

Year	SO_2 Emissions [short tons]			SO_2 Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007	With Rule (Fuel sulfur reduced to 15 ppm in 2010)	With fuel sulfur reduced to 500 ppm in 2007	With Rule
2000	167,094	167,094	167,094	0	0
2005	191,385	191,385	191,385	0	0
2007	194,003	93,229	93,229	100,774	100,774
2008	198,657	21,757	21,757	176,900	176,900
2009	203,311	22,267	22,267	181,044	181,044
2010	206,104	20,917	9,297	185,187	196,807
2011	210,737	21,387	1,032	189,350	209,705
2015	229,235	23,265	1,014	205,970	228,221
2020	252,089	25,584	1,005	226,505	251,084
2025	274,913	27,901	1,038	247,012	273,875
2030	297,573	30,200	1,096	267,373	296,477

Table 3.5-6b
Estimated National (50-State) SO_2
Emissions and Reductions From Nonroad Land-Based Diesel Engines

Year	SO_2 Emissions [short tons]			SO_2 Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007	With Rule (Fuel sulfur reduced to 15 ppm in 2010)	With fuel sulfur reduced to 500 ppm in 2007	With Rule
2000	167,999	167,999	167,999	0	0
2005	192,424	192,424	192,424	0	0
2007	195,057	93,735	93,735	101,321	101,321
2008	199,736	21,875	21,875	177,861	177,861
2009	204,416	22,388	22,388	182,028	182,028
2010	207,225	21,031	9,347	186,194	197,878
2011	211,884	21,504	1,038	190,380	210,846
2015	230,483	23,391	1,020	207,092	229,464
2020	253,464	25,724	1,011	227,740	252,453
2025	276,414	28,053	1,044	248,361	275,370
2030	299,199	30,365	1,102	268,834	298,098

The benefits in the early years of the program (i.e., pre-2010) are from reducing the diesel fuel sulfur level to 500 ppm. Reducing the diesel fuel sulfur level to 15 ppm in June of 2010 proportionately reduces SO_2 further. Total 50-state SO_2 emissions are reduced 298,000 tons with the proposed rule by 2030. Note that SO_2 emissions continue to increase over time due to the growth in the nonroad sector.

Nonroad diesel engines used in locomotives, commercial marine vessels, and recreational marine vessels are not affected by the emission standards of this proposal. SO_2 emissions from these engines would be reduced by the reductions in diesel fuel sulfur for these types of engines from an in-use average of 2400 ppm today to an in-use average of about 230 ppm in 2010. The estimated 48-state and 50-state reductions in SO_2 emissions from these engines based on the proposed change in diesel fuel sulfur are given in Tables 3.5-7a and 3.5-7b, respectively. Total 50-state SO_2 reductions reach 91,000 tons in 2030 for these diesel nonroad engine categories.

Tables 3.5-8a and 3.5-8b present the SO_2 emissions and reductions for all nonroad diesel categories combined. The 50-state results are also presented graphically in Figure 3.5-4. For all nonroad diesel categories combined, the estimated 50-state reductions in SO_2 emissions with the proposed rule are 334,000 tons in 2020, increasing to 389,000 tons in 2030. Simply reducing the fuel sulfur level to 500 ppm in 2007 would result in SO_2 reductions of 310,000 tons in 2020 and 360,000 tons in 2030.

Table 3.5-7a
Estimated National (48-State) SO_2 Reductions
From Locomotives, Commercial Marine, and Recreational Marine Diesel Engines

Year	SO_2 Reductions with Rule [short tons]			
	Locomotives	Commerical Marine Diesel Vessels	Recreational Marine Diesel Vessels	Total SO_2 Reductions
2000	0	0	0	0
2005	0	0	0	0
2007	26,058	14,569	1,546	42,173
2008	44,874	25,255	2,718	72,847
2009	45,184	25,533	2,784	73,501
2010	45,506	25,814	2,850	74,170
2011	46,282	26,100	2,916	75,298
2015	46,955	27,285	3,178	77,418
2020	48,383	28,866	3,508	80,757
2025	50,578	30,572	3,838	84,988
2030	52,873	32,415	4,167	89,455

Table 3.5-7b
Estimated National (50-State) SO_2 Reductions
From Locomotives, Commercial Marine, and Recreational Marine Diesel Engines

Year	SO_2 Reductions with Rule [short tons]			
	Locomotives	Commerical Marine Diesel Vessels	Recreational Marine Diesel Vessels	Total SO_2 Reductions
2000	0	0	0	0
2005	0	0	0	0
2007	26,094	15,326	1,556	42,977
2008	44,936	26,568	2,735	74,239
2009	45,246	26,860	2,801	74,907
2010	45,569	27,156	2,868	75,592
2011	46,346	27,457	2,934	76,737
2015	47,021	28,703	3,198	78,922
2020	48,450	30,367	3,530	82,346
2025	50,648	32,161	3,862	86,671
2030	52,946	34,100	4,193	91,239

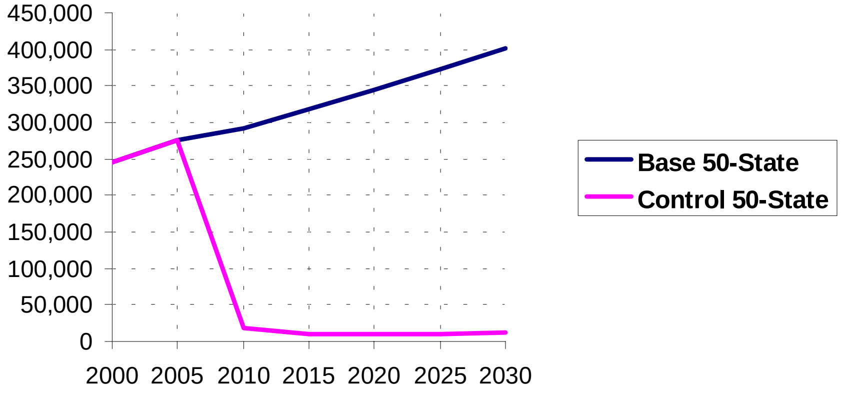
Table 3.5-8a
Estimated National (48-State) SO_2 Emissions and Reductions from Land-Based Nonroad, Locomotive, Commercial Marine, and Recreational Marine Vessels

Year	SO_2 Emissions [short tons]			SO_2 Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels
2000	243,333	243,333	243,333	0	0
2005	273,331	273,331	273,331	0	0
2007	275,101	132,153	132,153	142,948	142,948
2008	280,363	30,617	30,617	249,746	249,746
2009	285,750	31,206	31,206	254,543	254,543
2010	288,617	29,261	17,640	259,356	270,977
2011	294,504	29,857	9,502	264,648	285,003
2015	315,367	31,978	9,728	283,389	305,639
2020	341,941	34,679	10,100	307,262	331,840
2025	369,475	37,475	10,612	332,000	358,863
2030	397,109	40,281	11,176	356,828	385,932

Table 3.5-8b
Estimated National (50-State) SO_2 Emissions and Reductions from
Land-Based Nonroad, Locomotive, Commercial Marine, and Recreational Marine Vessels

Year	SO_2 Emissions [short tons]			SO_2 Reductions [short tons]	
	Without Rule	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels	With fuel sulfur reduced to 500 ppm in 2007	With fuel sulfur further reduced to 15 ppm in 2010 for land-based diesels
2000	245,712	245,712	245,712	0	0
2005	275,929	275,929	275,929	0	0
2007	277,699	133,401	133,401	144,298	144,298
2008	283,004	30,904	30,904	252,100	252,100
2009	288,434	31,499	31,499	256,935	256,935
2010	291,320	29,534	17,851	261,786	273,470
2011	297,252	30,135	9,669	267,117	287,583
2015	318,288	32,274	9,903	286,014	308,386
2020	345,084	34,998	10,285	310,086	334,799
2025	372,849	37,817	10,807	335,032	362,041
2030	400,720	40,647	11,383	360,073	389,337

Figure 3.5-4: Estimated SOx Benefits from Reducing Sulfur for Land-Based Nonroad Engines, CMVs, RMVs, and Locomotives



3.5.4 VOC and Air Toxics Reductions

Tables 3.5-9a and 3.5-9b show our projection of the 48-state and 50-state reductions in VOC emissions that EPA expects from implementing the proposed NMHC standards.

Although this proposal does not include specific standards for air toxics, these pollutants would be reduced through the implementation of the proposed NMHC standards. Tables 3.5-10a and 3.5-10b show our estimate of the proposed rule's beneficial impact on the key air toxics emissions of benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and acrolein. We base these numbers on the assumption that air toxic emissions are a constant fraction of hydrocarbon exhaust emissions.

Table 3.5-9a
VOC Reductions (48-State) from Land-Based Nonroad Diesel Engines

Calendar Year	VOC Without Rule [short tons]	VOC With Rule [short tons]	VOC Reductions With Rule [short tons]
2000	200,366	200,366	0
2005	163,193	163,193	0
2010	128,391	128,301	90
2015	105,800	97,013	8,788
2020	96,855	78,822	18,033
2025	95,144	70,520	24,624
2030	97,348	67,861	29,487

Table 3.5-9b
VOC Reductions (50-State) from Land-Based Nonroad Diesel Engines

Calendar Year	VOC Without Rule [short tons]	VOC With Rule [short tons]	VOC Reductions With Rule [short tons]
2000	201,386	201,386	0
2005	164,035	164,035	0
2010	129,063	128,973	91
2015	106,359	97,519	8,841
2020	97,378	79,238	18,141
2025	95,663	70,894	24,769
2030	97,882	68,223	29,660

Table 3.5-10a
Air Toxic Reductions (48-State) (tons/year)

Year		Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
2000	Base	4,007	23,643	10,619	401	601
	Control	4,007	23,643	10,619	401	601
	Reduction	0	0	0	0	0
2005	Base	3,264	19,257	8,649	326	490
	Control	3,264	19,257	8,649	326	490
	Reduction	0	0	0	0	0
2007	Base	2,990	17,643	7,924	299	449
	Control	2,990	17,643	7,924	299	449
	Reduction	0	0	0	0	0
2010	Base	2,568	15,150	6,805	257	385
	Control	2,566	15,140	6,800	257	385
	Reduction	2	11	5	0	0
2015	Base	2,116	12,484	5,607	212	317
	Control	1,940	11,448	5,142	194	291
	Reduction	176	1,037	466	18	26
2020	Base	1,937	11,429	5,133	194	291
	Control	1,576	9,301	4,178	158	236
	Reduction	361	2,128	956	36	55
2025	Base	1,903	11,227	5,043	190	285
	Control	1,410	8,321	3,738	141	212
	Reduction	492	2,906	1,305	49	73
2030	Base	1,947	11,487	5,159	195	292
	Control	1,357	8,008	3,597	136	204
	Reduction	590	3,479	1,563	59	88

Table 3.5-10b
Air Toxic Reductions (50-State) (tons/year)

Year		Benzene	Formaldehyde	Acetaldehyde	1,3-Butadiene	Acrolein
2000	Base	4,028	23,764	10,673	403	604
	Control	4,028	23,764	10,673	403	604
	Reduction	0	0	0	0	0
2005	Base	3,281	19,356	8,694	328	492
	Control	3,281	19,356	8,694	328	492
	Reduction	0	0	0	0	0
2007	Base	3,006	17,735	7,966	301	451
	Control	3,006	17,735	7,966	301	451
	Reduction	0	0	0	0	0
2010	Base	2,581	15,229	6,840	258	387
	Control	2,579	15,219	6,836	258	387
	Reduction	2	11	5	0	0
2015	Base	2,127	12,550	5,637	213	319
	Control	1,950	11,507	5,168	195	293
	Reduction	177	1,043	469	18	27
2020	Base	1,948	11,491	5,161	195	292
	Control	1,585	9,350	4,200	158	238
	Reduction	363	2,141	961	36	54
2025	Base	1,913	11,288	5,070	191	287
	Control	1,418	8,366	3,757	142	213
	Reduction	495	2,923	1,313	50	74
2030	Base	1,958	11,550	5,188	196	294
	Control	1,364	8,050	3,616	136	205
	Reduction	593	3,500	1,572	59	89

3.5.5 CO Reductions

Tables 3.5-11a and 3.5-11b show the estimated 48-state and 50-state emissions of CO from land-based diesel engines in five year increments from 2000 to 2030 with and without the proposed rule and the estimated emissions reductions. Although for most engines, Tier 4 does not revise the existing CO standards, CO is estimated to be reduced 90% with the advent of trap-equipped engines (corresponding to the start of 0.02 or 0.01 g/bhp-hr PM standards). By 2030, we estimate that 50-state CO emissions from these engines will be reduced 623,000 tons in that year.

CO emissions from locomotives, commercial marine diesel vessels, and recreational marine diesel vessels are not affected by this proposal.

Table 3.5-11a
Estimated National (48-State) CO
Emissions and Reductions From Nonroad Land-Based Diesel Engines

Year	CO Emissions Without Rule [short tons]	CO Emissions With Rule [short tons]	CO Reductions With Rule [short tons]
2000	923,886	923,886	0
2005	764,918	764,918	0
2010	684,552	684,552	0
2015	672,944	490,424	182,520
2020	700,017	318,530	381,487
2030	793,923	173,579	620,345

Table 3.5-11b
Estimated National (50-State) CO
Emissions and Reductions From Nonroad Land-Based Diesel Engines

Year	CO Emissions Without Rule [short tons]	CO Emissions With Rule [short tons]	CO Reductions With Rule [short tons]
2000	923,674	928,674	0
2005	768,838	768,838	0
2010	688,153	688,377	0
2015	676,570	492,974	183,596
2020	703,845	320,115	383,730
2030	798,316	174,465	623,851

3.6 Emission Inventories Used for Air Quality Modeling

The emissions inputs for the air quality modeling are required early in the analytical process, in order to be able to conduct the air quality modeling and present the results in this proposal. The air quality modeling was based on a preliminary control scenario. Since the preliminary control scenario was developed, we have gathered more information regarding the technical feasibility of the standards (see Section 3 of the preamble for this proposal and Chapter 4 of this document). As a result, we have revised the control scenario. We have also made minor changes to the baseline fuel sulfur levels. This section describes the changes in the inputs and resulting emissions inventories between the preliminary baseline and control scenarios used for the air quality modeling and the updated baseline and control scenarios in this proposal. This section will focus on the four nonroad diesel categories that are affected by the proposed standards and/or the fuel sulfur requirements: land-based diesel engines, recreational marine diesel engines, commercial marine diesel engines, and locomotives. There have been no changes to any other source categories (e.g., highway, stationary point and area sources). While these other source categories are not affected by the proposed rule, revisions to the inventories for these other source categories can impact air quality results.

The methodology used to develop the emissions inventories for the air quality modeling is first briefly described, followed by comparisons of the preliminary and proposed baseline and control inventories.

3.6.1 Methodology for Emission Inventory Preparation

Air quality modeling was performed for calendar years 1996, 2020, and 2030. For these years, county-level emission estimates were developed by Pechan under contract to EPA. These inventories account for county-level differences in fuel characteristics and temperature. The NONROAD model was used to generate the county-level emissions estimates for all nonroad sources, with the exception of commercial marine engines, locomotives, and aircraft. The methodology has been documented in detail.[10]

For the diesel nonroad categories affected by the proposed rule, the only fuel characteristic that affects emissions is the fuel sulfur level. The specific pollutants affected by fuel sulfur level are PM and SO_2. To develop the county-level emission estimates for each baseline and control inventory, one diesel fuel sulfur level was used to characterize all counties outside California. A separate diesel fuel sulfur level was used to characterize all counties within California. Diesel emissions as modeled are not affected by ambient temperature.

3.6.2 Baseline Inventories

Table 3.6-1 presents the preliminary 48-state baseline inventories used for the air quality modeling. These are an aggregation of the county-level results. Results expressed as short tons are presented for 1996, 2020, and 2030 for the land-based diesel, recreational marine diesel, commercial marine diesel, and locomotive categories. The pollutants include $PM_{2.5}$, NO_x, SO_2, VOC, and CO. VOC includes both exhaust and crankcase emissions.

Table 3.6-1
Modeled 48-State Baseline Emissions
Preliminary Baseline Used for Air Quality Modeling

Applications	Year	NO_x [short tons]	$PM_{2.5}$ [short tons]	SO_2 [short tons]	VOC [short tons]	CO [short tons]
Land-Based Diesel Engines	1996	1,583,641	178,500	172,175	221,398	1,010,501
	2020	1,144,686	127,755	308,075	97,113	702,145
	2030	1,231,981	143,185	360,933	97,345	793,899
Recreational Marine Diesel Engines	1996	19,438	511	2,535	803	3,215
	2020	34,814	876	4,562	1,327	5,537
	2030	41,246	1,021	5,418	1,528	6,464
Commercial Marine Diesel Engines	1996	959,704	37,203	37,252	31,545	126,382
	2020	819,201	42,054	43,028	37,290	159,900
	2030	814,827	46,185	48,308	41,354	176,533
Locomotives	1996	921,556	22,396	57,979	48,381	112,171
	2020	612,722	17,683	62,843	36,546	119,302
	2030	534,520	16,988	70,436	31,644	119,302

For the proposed baseline inventories, we have made minor changes to the diesel fuel sulfur levels. The diesel fuel sulfur inputs used for the preliminary and proposed baseline inventories are provided in Table 3.6-2. The diesel fuel sulfur level is now reduced from 2500ppm to roughly 2300ppm, beginning in 2006. Both the preliminary and proposed sulfur levels account for spillover of highway fuel, but the preliminary sulfur levels did not properly account for the 15ppm highway fuel sulfur content control phase-in beginning in 2006.

There have also been reductions to the fuel volumes assigned to locomotives and commercial marine vessels. For the preliminary inventory development, railroad distillate and vessel bunkering distillate values were taken from the EIA Fuel and Kerosene Supply 2000 report. Fuel consumption specific to locomotives was calculated by subtracting the rail maintenance fuel consumption as generated by the draft NONROAD2002 model from the EIA railroad distillate estimates. Similarly, fuel consumption specific to commercial marine vessels was calculated by subtracting the recreational marine fuel consumption as generated by the draft NONROAD2002 model from the EIA vessel bunkering estimates.

For the proposed inventory, the EIA railroad distillate and vessel bunkering distillate estimates were first adjusted to estimate the fraction of distillate that is diesel fuel. The diesel fractions used are 0.95 for railroad distillate and 0.90 for vessel bunkering distillate. Fuel consumption estimates from rail maintenance and recreational marine engines were then subtracted. The estimate of rail maintenance fuel consumption was also revised by assuming these engines consume one percent of the total railroad diesel fuel estimate, rather than using the estimate derived from draft NONROAD2002. The revised estimate of rail maintenance fuel consumption is roughly half of the NONROAD-derived estimate; however, the rail maintenance portion of the total railroad diesel fuel consumption is small, so this change alone does not significantly affect the resulting locomotive estimate. The estimate of recreational marine fuel consumption continues to be that generated from the draft NONROAD2002 model. The derivation of diesel fractions and the revised estimate of rail maintenance fuel consumption is documented in Chapter 7.

As a result, the corrections to fuel sulfur levels and locomotive and commercial marine fuel volumes will reduce the PM and SO_2 baseline inventories in 2020 and 2030.

Table 3.6-2
Modeled Baseline In-Use Diesel Fuel Sulfur Content
Proposed Baseline vs Preliminary Baseline Used for Air Quality Modeling

Applications	Proposed Baseline		Preliminary Baseline	
	Fuel Sulfur ppm	Calendar Year	Fuel Sulfur ppm	Calendar Year
Land-Based Diesel Engines	2318	through 2005	2500[a]	all years
	2271	2006		
	2237	2007-2009		
	2217	2010+		
Commercial and Recreational Marine Engines and Locomotives	2396	through 2005	2500[a]	all years
	2352	2006		
	2321	2007-2009		
	2302	2010+		

[a] 2500ppm is the 48-state average diesel fuel sulfur level, based on 2700ppm in 47 states and 120ppm in California.

For the commercial marine diesel and locomotive categories, revised PM and SO_2 inventories were generated for the proposed baseline scenarios. For the land-based diesel and recreational marine diesel categories, it was not possible to generate revised county-level baseline inventories due to time and resource constraints. Instead, for the land-based diesel and recreational marine diesel categories, national level NONROAD model runs were used as the basis for comparison of the preliminary and proposed baseline scenarios. National level model runs were done using the 48-state average fuel sulfur levels for both the preliminary and proposed baseline scenarios in 1996, 2020 and 2030.

To examine the feasibility of using national level model results, Table 3.6-3 first provides a comparison of the 48-state emissions derived from national level model runs to those derived from a sum of county level runs for the same preliminary baseline scenario. The county-level results were taken from Table 3.6-1. The national level and sum of county level results are quite similar for NO_x, VOC, and CO. Use of the national level model runs lowers the emissions baseline slightly for SO_2, and less so for PM. This is expected, since diesel NO_x, VOC, and CO emissions are insensitive to county-level differences in fuel characteristics and temperature. PM and SO_2 are sensitive to fuel sulfur levels, with SO_2 exhibiting the most sensitivity.

Table 3.6-4 compares the proposed and preliminary 48-state baseline scenario inventories for land-based diesel engines, recreational marine diesel engines, commercial marine diesel engines, and locomotives. The national level model run results are used as the basis for comparison for the land-based diesel and recreational marine diesel categories. Results are only presented for $PM_{2.5}$ and SO_2 emissions, since these are the only pollutants affected by the changes.

$PM_{2.5}$ emissions are reduced roughly 2% with the proposed baseline scenario in 2020 and 2030, while SO_2 is reduced 13%. These reductions to the baseline will serve to decrease the emission reductions of the rule for $PM_{2.5}$ and SO_2.

Table 3.6-3
Modeled 48-State Emissions for Preliminary Baseline Scenario Used for Air Quality Modeling
Comparison of Results Derived from National Level Model Runs vs. Sum of County Level Model Runs

Applications	Year	NO$_x$ [short tons]			PM$_{2.5}$ [short tons]			SO$_2$ [short tons]		
		National Level	County Level	% Difference	National Level	County Level	% Difference	National Level	County Level	% Difference
Land-Based Diesel Engines	1996	1,583,664	1,583,641	0.0%	177,375	178,500	-0.6%	159,540	172,175	-7.3%
	2020	1,140,727	1,144,686	-0.3%	126,720	127,755	-0.8%	284,268	308,075	-7.7%
	2030	1,231,995	1,231,981	0.0%	142,342	143,185	-0.6%	335,558	360,933	-7.0%
Recreational Marine Diesel Engines	1996	19,440	19,438	0.0%	494	511	-3.3%	2,349	2,535	-7.4%
	2020	34,817	34,814	0.0%	848	876	-3.2%	4,239	4,562	-7.1%
	2030	41,250	41,246	0.0%	988	1,021	-3.2%	5,035	5,418	-7.1%

Table 3.6-3, continued

Applications	Year	VOC [short tons]			CO [short tons]		
		National Level	County Level	% Difference	National Level	County Level	% Difference
Land-Based Diesel Engines	1996	221,403	221,398	0.0%	1,010,501	1,010,501	0.0%
	2020	96,855	97,113	-0.3%	700,017	702,145	-0.3%
	2030	97,348	97,345	0.0%	793,923	793,899	0.0%
Recreational Marine Diesel Engines	1996	803	803	0.0%	3,215	3,215	0.0%
	2020	1,328	1,327	0.0%	5,538	5,537	0.0%
	2030	1,528	1,528	0.0%	6,465	6,464	0.0%

Table 3.6-4
Modeled 48-State Baseline $PM_{2.5}$ and SO_2 Emission Reductions Due to Changes in Baseline

Applications	Year	$PM_{2.5}$ Emissions [short tons]			SO_2 [short tons]		
		Proposed	Preliminary	Reduction	Proposed	Preliminary	Reduction
Land-Based Diesel Engines	1996	176,510	177,375	865 (0.5%)	147,926	159,540	11,614 (7.3%)
	2020	124,334	126,720	2,386 (1.9%)	252,089	284,268	32,179 (11.3%)
	2030	139,527	142,342	2,815 (2.0%)	297,573	335,558	37,985 (11.3%)
Recreational Marine Diesel Engines	1996	487	494	7 (1.4%)	2,251	2,349	98 (4.2%)
	2020	823	848	25 (2.9%)	3,903	4,239	336 (7.9%)
	2030	958	988	30 (3.0%)	4,636	5,035	399 (7.9%)
Commercial Marine Diesel Engines	1996	36,367	37,203	836 (2.2%)	25,948	37,252	11,304 (30.3%)
	2020	41,365	42,054	689 (1.6%)	32,117	43,028	10,911 (25.4%)
	2030	45,411	46,185	774 (1.7%)	36,068	48,308	12,240 (25.3%)
Locomotives	1996	20,937	22,396	1,459 (6.5%)	50,534	57,979	7,445 (12.8%)
	2020	16,727	17,683	956 (5.4%)	53,832	62,843	9,011 (14.3%)
	2030	15,670	16,988	1,318 (7.8%)	58,832	70,436	11,604 (16.5%)
Total	1996	234,301	237,468	3,167 (1.3%)	226,659	257,120	30,461 (11.8%)
	2020	183,249	187,305	4,056 (2.2%)	341,941	394,378	52,437 (13.3%)
	2030	201,566	206,503	4,937 (2.4%)	397,109	459,337	62,228 (13.5%)

[a] Based on 48-state national runs for land-based and recreational marine categories. Based on 48-state sum of county level runs for commercial marine and locomotive engines.

3.6.3 Control Inventories

Table 3.6-5 presents the preliminary 48-state control inventories used for the air quality modeling. These are an aggregation of the county-level results. Results expressed as short tons are presented for 2020 and 2030 for the land-based diesel, recreational marine diesel, commercial marine diesel, and locomotive categories. Results are not presented for 1996, since controls will only affect future year emission estimates.

Table 3.6-5
Modeled 48-State Controlled Emissions
Preliminary Control Scenario Used for Air Quality Modeling

Applications	Year	NO_x [short tons]	$PM_{2.5}$ [short tons]	SO_2 [short tons]	VOC [short tons]	CO [short tons]
Land-Based Diesel Engines	2020	481,068	36,477	3,340	73,941	249,734
	2030	222,237	14,112	1,159	63,285	133,604
Recreational Marine Diesel Engines	2020	34,814	552	20	1,327	5,537
	2030	41,246	636	24	1,528	6,464
Commercial Marine Diesel Engines	2020	819,201	38,882	184	37,290	159,900
	2030	814,827	42,625	206	41,354	176,533
Locomotives	2020	612,722	13,051	272	36,546	119,302
	2030	534,520	11,798	305	31,644	119,302

The certification standards used for the preliminary and proposed control scenarios are provided in Tables 3.6-6 and 3.6-7, respectively. In general, the preliminary control scenario is more stringent in terms of levels and effective model years for PM and NO_x than the proposed control scenario for all horsepower categories. The NMHC standard is 0.14 g/bhp-hr with both scenarios, although the phase-in of this standard is later in the proposed control scenario. The CO standards are unchanged in both control scenarios, although CO is assumed to be reduced 90% in both scenarios with the advent of trap-equipped engines (corresponding to the start of 0.02 or 0.01 g/bhp-hr PM standards). As a result, the proposed standards will increase the emissions of PM, NO_x, NMHC, and CO in 2020 and 2030 relative to the preliminary standards.

Table 3.6-6
Preliminary Tier 4 Exhaust Emissions Certification Standards Used for Air Quality Modeling

Engine Power	Emission Standards g/bhp-hr					Model Year
	transitional or final	PM	NO_x	NMHC	CO	
hp <25	transitional	0.01	5.6 [a,b]		6.0/4.9 [b]	2010
	final	0.01	0.30	0.14	6.0/4.9 [b]	2012
25 ≤ hp < 50	transitional	0.01	5.6 [a,b]		4.1 [b]	2010
	final	0.01	0.30	0.14	4.1 [b]	2012
50 ≤ hp < 100	transitional	0.01	3.5 [a,b]		3.7 [b]	2010
	final	0.01	0.30	0.14	3.7 [b]	2012
100 ≤ hp < 175	transitional	0.01	3.0 [a,b]		3.7 [b]	2010
	final	0.01	0.30	0.14	3.7 [b]	2012
175 ≤ hp < 750	transitional	0.01	3.0 [a,b]		2.6 [b]	2009
	final	0.01	0.30	0.14	2.6 [b]	2011
hp ≥ 750	transitional	0.01	4.8 [a,b]		2.6 [b]	2009
	final	0.01	0.30	0.14	2.6 [b]	2011

[a] This is a combined NMHC + NO_x standard.

[b] This emission standard is unchanged from the level that applies in the previous model year. For engines below 25 hp, the CO standard is 6.0 g/bhp-hr for engines below 11 hp and 4.9 g/bhp-hr for engines at or above 11 hp.

Table 3.6-7
Proposed Tier 4 Exhaust Emissions Certification Standards

Engine Power	Emissions Standard (g/bhp-hr)[a]					Model Year
	transitional or final	PM	NO_x	NMHC	CO	
hp <25	final	0.30	5.6 [b,c]		4.9	2008
25 ≤ hp < 75	transitional[d]	0.22	5.6/3.5 [b,c]		3.7	2008
	final	0.02	3.5 [b]		3.7 [c]	2013
75 ≤ hp < 175	transitional	0.01 (100%)	0.30 (50%)	0.14 (50%)	3.7 [c]	2012-2013
	final	0.01 (100%)	0.30 (100%)	0.14 (100%)	3.7 [c]	2014
175 ≤ hp < 750	transitional	0.01 (100%)	0.30 (50%)	0.14 (50%)	2.6 [c]	2011-2013
	final	0.01 (100%)	0.30 (100%)	0.14 (100%)	2.6 [c]	2014
hp ≥ 750	transitional	0.01 (50%)	0.30 (50%)	0.14 (50%)	2.6 [c]	2011-2013
	final	0.01 (100%)	0.30 (100%)	0.14 (100%)	2.6 [c]	2014

[a] Percentages are model year sales fractions required to comply with the indicated standard.

[b] This is a combined NMHC + NO_x standard.

[c] This emissions standard level is unchanged from the level that applies in the previous model year. For 25-75 hp engines, the transitional NMHC + NO_x standard is 5.6 g/bhp-hr for engines below 50 hp and 3.5 g/bhp-hr for engines at or above 50 hp.

[d] Manufacturers may optionally skip the transitional standards for 25-75 hp engines; the final standards would then take effect for these engines in the 2012 model year.

The diesel fuel sulfur inputs used for the preliminary and proposed control scenarios are provided in Tables 3.6-8 and 3.6-9, respectively. For land-based diesel engines, the modeled in-use diesel fuel sulfur content is 11ppm in 2020 and 2030 for both scenarios. For recreational marine engines, commercial marine engines and locomotives, the modeled in-use diesel fuel sulfur content is 11ppm in 2020 and 2030 for the preliminary control scenario, but 233 ppm in 2020 and 2030 for the proposed control scenario. As a result, the proposed fuel sulfur levels will serve to increase the PM and SO_2 control inventories for the recreational marine, commercial marine, and locomotive categories in 2020 and 2030. This will be offset slightly by the reduced fuel volumes assigned to the commercial marine and locomotive categories.

Table 3.6-8
Modeled 48-State & 50-State In-Use
Diesel Fuel Sulfur Content Used for Air Quality Modeling

Applications	Standards	Modeled In-Use Fuel Sulfur Content, ppm	Calendar Year
All Diesel Categories	Baseline + hwy 500 ppm "spillover"	2500	through 2005
	Baseline + hwy 15 ppm "spillover"	2400	2006-2007
	June intro of 15 ppm	1006	2008
	Final 15 ppm standard	11	2009

Table 3.6-9
Modeled 48-State & 50-State In-Use Diesel Fuel Sulfur Content for Proposed Standards

Applications	Standards	Modeled In-Use Fuel Sulfur Content, ppm	Calendar Year
Land-based, all power ranges	Baseline	2318	through 2005
		2271	2006
	June intro of 500 ppm	1075	2007
	500 ppm standard	245	2008-2009
	June intro of 15 ppm	100	2010
	Final 15 ppm standard	11	2011+
Recreational and Commercial Marine Diesel Engines and Locomotives	Baseline	2396	through 2005
		2352	2006
	June intro of 500 ppm	1114	2007
	Final 500 ppm standard	252	2008-2009
		233	2010+

To adjust PM emissions for these in-use fuel sulfur levels, the adjustment is made relative to the certification diesel fuel sulfur levels in the model. The modeled certification diesel fuel sulfur inputs used for the preliminary and proposed control scenarios are provided in Tables 3.6-10 and 3.6-11, respectively. For 2020 and 2030, the certification diesel fuel sulfur levels are the same for both the preliminary and proposed control scenarios.

For the commercial marine diesel and locomotive categories, inventories were generated for the proposed control scenarios, using the fuel volume and fuel sulfur level estimates. For the land-based diesel and recreational marine diesel categories, it was not possible to generate revised county-level control inventories. Instead, for the land-based diesel and recreational marine diesel categories, national level NONROAD model runs were used as the basis for comparison of the preliminary and proposed control scenarios. National level model runs were done using the 48-state average fuel sulfur levels for both the preliminary and proposed control scenarios in 2020 and 2030.

To examine the feasibility of using national level model results, Table 3.6-12 first provides a comparison of the 48-state emissions derived from national level model runs to those derived from a sum of county level runs for the same preliminary control scenario. The county-level results were taken from Table 3.6-5. The national level and sum of county level results are quite similar. This is expected, since diesel NO_x, VOC, and CO emissions are insensitive to county-level differences in fuel characteristics and temperature. PM and SO_2 are sensitive to fuel sulfur levels, with SO_2 exhibiting the most sensitivity.

Table 3.6-13 compares the proposed and preliminary 48-state control scenario inventories for land-based diesel engines, recreational marine diesel engines, commercial marine diesel engines, and locomotives. The national level model run results are used as the basis for comparison for the land-based diesel and recreational marine diesel categories. Results are presented for $PM_{2.5}$, NO_x, SO_2, VOC, and CO emissions.

For land-based diesel engines, emissions of $PM_{2.5}$, NO_x, VOC, and CO emissions are higher for the proposed control scenario. This is due to the less stringent emission standards. There were no differences in either the in-use or certification diesel fuel sulfur levels in 2020 and 2030 for this category. The minor difference in SO_2 emissions between the proposed and preliminary scenarios is attributed to differences in aggregation of county-level runs compared to using one national level run.

The recreational marine, commercial marine, and locomotive categories are not controlled in either scenario; however, the in-use fuel sulfur level is 11ppm for the preliminary control scenario and 233 ppm for the proposed control scenario. This affects the PM and SO_2 emissions. Accordingly, the PM and SO_2 emissions for these categories are higher for the proposed control scenario.

Table 3.6-10
Modeled Certification Diesel Fuel Sulfur Content Used for Air Quality Modeling

Engine Power	Standards	Modeled Certification Fuel Sulfur Content, PPM	Model Year
hp <50	Tier 2	2000	through 2009
	Tier 4[a]	15	2010
50 ≤ hp < 175	Tier 3	2000	through 2009
	Tier 4[a]	15	2010
175 ≤ hp < 750	Tier 3	2000	through 2008
	Tier 4[a]	15	2009
hp ≥ 750	Tier 2	2000	through 2008
	Tier 4[a]	15	2009

[a] Tier 4 refers to both transitional and final standards.

Table 3.6-11
Modeled Certification Diesel Fuel Sulfur Content for Proposed Standards

Engine Power	Standards	Modeled Certification Fuel Sulfur Content, PPM	Model Year
hp <75	Tier 2	2000	through 2007
	transitional	500	2008
	final	15	2013
75 ≤ hp < 100	Tier 3 transitional[a]	500	2008-2011
	final	15	2012
100 ≤ hp < 175	Tier 3	2000	2007-2011
	final	15	2012
175 ≤ hp < 750	Tier 3	2000	2006-2010
	final	15	2011
hp ≥ 750	Tier 2	2000	2006-2010
	transitional[b]	50% 2000 50% 15	2011-2013
	final	15	2014

[a] The emission standard here is still Tier 3 as in the Baseline case, but since the Tier 3 standard begins in 2008 for 50-100 hp engines it is assumed that this new technology introduction would allow manufacturers to take advantage of the availability of 500 ppm fuel that year.

[b] The engines remaining at the Tier 2 level would be allowed to continue certifying on the same fuel as earlier Tier 2 engines, but those meeting the Tier 4 0.01 PM standard are assumed to certify on 15 ppm fuel.

Table 3.6-12
Modeled 48-State Emissions for Preliminary Control Scenario Used for Air Quality Modeling
Comparison of Results Derived from National Level Model Runs vs. Sum of County Level Model Runs

Applications	Year	NO$_x$ [short tons]			PM$_{2.5}$ [short tons]			SO$_2$ [short tons]		
		National Level	County Level	% Difference	National Level	County Level	% Difference	National Level	County Level	% Difference
Land-Based Diesel Engines	2020	477,100	481,068	-0.8%	35,991	36,477	-1.3%	968	1,040	-6.9%
	2030	222,238	222,237	0.0%	14,031	14,112	-0.6%	1,078	1,159	-7.0%
Recreational Marine Diesel Engines	2020	34,817	34,814	0.0%	535	552	-3.1%	19	20	-5.0%
	2030	41,250	41,246	0.0%	616	636	-3.1%	22	24	-8.3%

Applications	Year	VOC [short tons]			CO [short tons]		
		National Level	County Level	% Difference	National Level	County Level	% Difference
Land-Based Diesel Engines	2020	74,423	73,941	0.7%	247,593	249,734	-0.9%
	2030	64,329	63,285	1.6%	133,606	133,604	0.0%
Recreational Marine Diesel Engines	2020	1,328	1,327	0.1%	5,538	5,537	0.0%
	2030	1,528	1,528	0.0%	6,465	6,464	0.0%

Table 3.6-13
Modeled 48-State Controlled Emissions
Emissions Impact Due to Changes in Control Scenario

Applications	Year	NO_x [short tons]			$PM_{2.5}$ [short tons]			SO_2 [short tons]		
		Proposed	Preliminary	Difference	Proposed	Preliminary	Difference	Proposed	Preliminary	Difference
Land-Based Diesel Engines	2020	637,025	477,100	159,925 (+33.5%)	45,057	35,991	9,066 (+25.2%)	1,005	968	37 (+3.8%)
	2030	410,084	222,238	188,264 (+84.7%)	19,239	14,031	5,208 (+37.1%)	1,096	1,078	18 (+1.7%)
Recreational Marine Diesel Engines	2020	34,817	34,817	0 (0.0%)	563	535	28 (+5.2%)	395	19	376 (+1979%)
	2030	41,250	41,250	0 (0.0%)	650	616	34 (+5.5%)	469	22	447 (+2032%)
Commercial Marine Diesel Engines	2020	819,201	819,201	0 (0.0%)	39,228	38,882	346 (+0.9%)	3,251	184	3,067 (+1667%)
	2030	814,827	814,827	0 (0.0%)	43,012	42,625	387 (+0.9%)	3,653	206	3,447 (+1673%)
Locomotives	2020	612,722	612,722	0 (0.0%)	13,147	13,051	96 (+0.7%)	5,449	272	5,177 (+1903%)
	2030	534,520	534,520	0 (0.0%)	11,756	11,798	42 (-0.4%)	5,959	305	5,654 (+1854%)

Table 3.6-13 (cont.)
Modeled 48-State Controlled Emissions Impact Due to Changes in Control Scenario

Applications	Year	VOC [short tons]			CO [short tons]		
		Proposed	Preliminary	Difference	Proposed	Preliminary	Difference
Land-Based Diesel Engines	2020	78,822	74,423	4,399 (+5.9%)	318,530	247,593	70,937 (+28.7%)
	2030	67,861	64,329	3,532 (+5.5%)	173,579	133,606	39,973 (+29.9%)
Recreational Marine Diesel Engines	2020	1,328	1,328	0 (0.0%)	5,538	5,538	0 (0.0%)
	2030	1,528	1,528	0 (0.0%)	6,465	6,465	0 (0.0%)
Commercial Marine Diesel Engines	2020	37,290	37,290	0 (0.0%)	159,900	159,900	0 (0.0%)
	2030	41,354	41,354	0 (0.0%)	176,533	176,533	0 (0.0%)
Locomotives	2020	36,546	36,546	0 (0.0%)	119,302	119,302	0 (0.0%)
	2030	31,644	31,644	0 (0.0%)	119,312	119,312	0 (0.0%)

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CHAPTER 4: Technologies and Test Procedures for Low-Emission Engines

4.1 Feasibility of Emission Standards

This section of Chapter 4 documents the technical feasibility analysis we conducted in developing the proposed Tier 4 emissions standards for nonroad diesel engine. The proposed standards and a summary of this analysis can be found in Section III of the preamble. This analysis incorporates recent Agency analyses of diesel emission control technologies for on-highway vehicles and expands those analyses with more recent data and additional analysis specific to the application of technology to nonroad diesel engines.[1,2]

The section is organized into subsections describing diesel emission control technologies, issues specific to the application of these technologies to new nonroad engines, specific analyses for engines within distinct horsepower categories (<25 hp, 25 - 75 hp, and >75 hp) and an analysis of the need for low sulfur diesel fuel (15 ppm sulfur) to enable these emission control technologies.

For the past 30 or more years, emission control development for gasoline vehicles and engines has concentrated most aggressively on exhaust emission control devices. These devices currently provide as much as or more than 95 percent of the emission control on a gasoline vehicle. In contrast, the emission control development work for nonroad and on-highway diesels has concentrated on improvements to the engine itself to limit the emissions leaving the combustion chamber.

However, during the past 15 years, more development effort has been put into catalytic exhaust emission control devices for diesel engines, particularly in the area of particulate matter (PM) control. Those developments, and recent developments in diesel NOx exhaust emission control devices, make the widespread commercial use of diesel exhaust emission controls feasible. EPA has recently set new emission standards for on-highway diesel vehicles based on the emission reduction potential of these devices. Through use of these devices, we believe emissions control similar to that attained by gasoline three-way-catalyst applications will be possible for diesel powered on-highway vehicles and nonroad equipment. However, without low sulfur diesel fuel, these technologies cannot be implemented.

4.1.1 PM Control Technologies

Particulate matter from diesel engines is made of three components;

- solid carbon soot,
- volatile and semi-volatile organic matter, and
- sulfate.

The formation of the solid carbon soot portion of PM is inherent in diesel engines due to the heterogenous distribution of fuel and air in a diesel combustion system. Diesel combustion is designed to allow for overall lean (excess oxygen) combustion giving good efficiencies and low CO and HC emissions with a small region of rich (excess fuel) combustion within the fuel injection plume. It is within this excess fuel region of the combustion that PM is formed when high temperatures and a lack of oxygen cause the fuel to pyrolize, forming soot. Much of the soot formed in the engine is burned during the combustion process as the soot is mixed with oxygen in the cylinder at high temperatures. Any soot that is not fully burned before the exhaust valve is opened will be emitted form the engine as diesel PM.

The volatile and semi-volatile organic material in diesel PM is often simply referred to as the soluble organic fraction (SOF) in reference to a test method used to measure its level. SOF is primarily composed of engine oil which passes through the engine with no or only partial oxidation and which condenses in the atmosphere to form PM. The SOF portion of diesel PM can be reduced through reductions in engine oil consumption and through oxidation of the SOF catalytically in the exhaust.

The sulfate portion of diesel PM is formed from sulfur present in diesel fuel and engine lubricating oil that oxidizes to form sulfuric acid (H_2SO_4) and then condenses in the atmosphere to form sulfate PM. Approximately two percent of the sulfur that enters a diesel engine from the fuel is emitted directly from the engine as sulfate PM.[3] The balance of the sulfur content is emitted from the engine as SO2. Oxidation catalyst technologies applied to control the SOF and soot portions of diesel PM can inadvertently oxidize SO2 in the exhaust to form sulfate PM. The oxidation of SO2 by oxidation catalysts to form sulfate PM is often called sulfate make. Without low sulfur diesel fuel, oxidation catalyst technology to control diesel PM is limited by the formation of sulfate PM in the exhaust as discussed in more detail in the discussion of the need for low sulfur fuel below.

4.1.1.1 In-Cylinder PM Control

The soot portion of PM emissions can be reduced by increasing the availability of oxygen within the cylinder for soot oxidation during combustion. Oxygen can be made more available by either increasing the oxygen content in cylinder or by increasing the mixing of the fuel and oxygen in-cylinder. A number of technologies exist that can influence oxygen content and in-cylinder mixing including improved fuel injection systems, air management systems, and combustion system designs. Many of these PM reducing technologies offer better control of combustion in general, and better utilization of fuel allowing for improvements in fuel efficiency concurrent with reductions in PM emissions. Improvements in combustion technologies and refinements of these systems is an ongoing effort for on-highway engines and for some nonroad engines where emission standards or high fuel use encourage their introduction. The application of better combustion system technologies across the broad range of nonroad engines in order to meet the new emission standards proposed here offers an opportunity for significant reductions in engine-out PM emissions and possibly for reductions in fuel consumption.

Another means to reduce the soot portion of diesel PM engine-out is to operate the diesel (compression-ignited) engine with a homogenous method of operation rather than the typical heterogenous operation. In homogenous diesel combustion, also called premixed diesel combustion, the fuel is dispersed evenly with the air throughout the combustion system. This means there are no fuel rich / oxygen deprived regions of the system where fuel can be pyrolized rather than burned. Rather, combustion occurs globally initiating at an indeterminate number of locations. Because there are no fuel rich / oxygen deprived regions in homogenous combustion, the carbon (soot) PM emissions are eliminated. The resulting PM emissions are very low, consisting primarily of SOF and sulfate.

Homogenous diesel combustion has been under development for more than twenty years, yet it is still unable to overcome a number of developmental issues.[4,5] Fundamental among these issues is the ability to control the start of combustion.[6] Conventional diesel engines control the start of combustion by controlling the start of fuel injection: injection timing control. Homogenous diesel combustion systems cannot readily use fuel injection timing to control the start of combustion because it is difficult to inject fuel into the engine without initiating combustion. If combustion is initiated while the fuel is being injected, the engine will operate under heterogenous combustion resulting in high PM emissions. Techniques used to delay the start of combustion such as decreasing intake air temperatures or reducing the engines compression ratio can lead to misfire, a failure to ignited the fuel at all. Engine misfire results in no engine power and high hydrocarbon (raw fuel) emissions. Conversely, techniques to advance the start of combustion such as increasing intake air temperatures or increasing the engine compression ratio can lead to premature uncontrolled combustion called engine knock. Engine knock causes exceedingly high in-cylinder pressures which can irreversibly damage a diesel engine at all but low load conditions.

Controlled homogenous combustion is possible with a diesel engine under certain circumstances, and is used in limited portions of engine operation by some engine manufacturers. Nissan, a passenger car manufacturer, has developed a modified version of premixed combustion that they call modulated-kinetics, or MK, combustion.[7,8] When operated under MK combustion the PM and NOx emissions of the engine are dramatically decreased. Unfortunately, the range of engine operation for which the MK combustion process can function is limited to low load conditions. At higher engine loads the combustion process is not stable and the engine reverts to operation with conventional diesel combustion. This dual mode operation allows the engine to benefit from the homogenous combustion approach when possible, while still providing the full range of engine operation. Other approaches that are similarly limited to low load engine operation have been proposed in order to produce a dual combustion mode engine.[9,1011]

4.1.1.2 Diesel Oxidation Catalysts (DOCs)

Diesel oxidation catalyst (DOCs) are the most common form of diesel aftertreatment technology today and have been used for compliance with the PM standards for some on-highway engines since the early 1990s. DOCs reduce diesel PM by oxidizing a small fraction of the soot emissions and a significant portion of the SOF emissions. Total DOC effectiveness to reduce PM emissions is normally limited to approximately 30 percent because the SOF portion of diesel PM for modern diesel engines is typically less than 30 percent and because the DOC increases sulfate emissions, reducing the overall effectiveness of the catalyst. Limiting fuel sulfur levels to 15ppm allows DOCs to be designed for maximum effectiveness (nearly 100% control of SOF with highly active catalyst technologies) since their control effectiveness is not reduced by sulfate make (i.e., their sulfate make rate is high but because the sulfur level in the fuel is low the resulting PM emissions are well controlled).

DOC effectiveness to control HC and CO emissions are directly related to the “activity” of the catalyst material used in DOC washcoating. Highly active (hence effective) DOCs can reduce HC emissions by 97 percent while low activity catalysts realize approximately 50 percent HC control.[12] Today, highly active DOC formulations cannot be used for NMHC and CO control because of sulfur in current diesel fuel which will lead to unacceptable sulfate PM emissions as discussed later in this section.

DOCs are also very effective at reducing the air toxic emissions from diesel engines. Test data shows that emissions of toxics such as polycyclic aromatic hydrocarbons (PAHs) can be reduced by more than 80 percent with a DOC.[13]

DOCs are ineffective at controlling the solid carbon soot portion of PM. The solid (soot) typically constitutes 60 to 90 percent of the total diesel PM. Therefore, even with 15 ppm sulfur fuel DOCs would not be able to achieve the level of PM control needed to meet the standard proposed today.

4.1.1.3 Catalyzed Diesel Particulate Filters (CDPFs)

4.1.1.3.1 CDPF PM and HC Control Effectiveness

Emission levels from CDPFs are determined by a number of factors. Filtering efficiencies for solid particle emissions like soot are determined by the characteristics of the PM filter, including wall thickness and pore size. Filtering efficiencies for diesel soot can be as high as 99 percent with the appropriate filter design.[14] Given an appropriate PM filter design the contribution of the soot portion of PM to the total PM emissions can be negligible (less than 0.001 g/bhp-hr). This level of soot emission control is not dependent on engine test cycle or operating conditions due to the mechanical filtration characteristics of the particulate filter.

Control of the SOF portion of diesel soot is accomplished on a CDPF through catalytic oxidation. The SOF portion of diesel PM consists of primarily gas phase hydrocarbons in engine exhaust due to the high temperatures and only forms particulate in the environment when it condenses. Catalytic materials applied to CDPFs can oxidize a substantial fraction of the SOF in diesel PM just as the SOF portion would be oxidized by a DOC. However, we believe that for engines with very high SOF emissions the emission rate may be higher than can be handled by a conventionally sized catalyst resulting in higher than zero SOF emissions. If a manufacturer’s base engine technology has high oil consumption rates, and therefore high engine-out SOF emissions (i.e., higher than 0.04 g/bhp-hr), compliance with the 0.01 g/bhp-hr emission standard proposed today may require additional technology beyond the application of a CDPF system alone.[A]

Modern on-highway diesel engines have controlled SOF emission rates in order to comply with the existing 0.1 g/bhp-hr emission standards. Typically the SOF portion of PM from a modern on-highway diesel engine contributes less than 0.02 g/bhp-hr to the total PM emissions. This level of SOF control is accomplished by controlling oil consumption through the use of engine modifications (e.g., piston ring design, the use of 4-valve heads, the use of valve stem seals, etc.).[15] Nonroad diesel engines may similarly need to control engine-out SOF emissions in order to comply with the standard proposed today. The means to control engine-out SOF emissions are well known and have additional benefits, as they decrease oil consumption reducing operating costs. With good engine-out SOF control (i.e., engine-out SOF < 0.02 g/bhp-hr) and the application of catalytic material to the DPF,

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[A] SOF oxidation efficiency is typically better than 80 percent and can be better than 90 percent. Given a base engine SOF rate of 0.04 g/bhp-hr and an 80 percent SOF reduction a tailpipe emission of 0.008 can be estimated from SOF alone. This level may be too high to comply with a 0.01 g/bhp-hr standard once the other constituents of diesel PM (soot and sulfate) are added. In this case, SOF emissions will need to be reduced engine-out or SOF control greater than 90 percent will need to be realized by the CDPF.

SOF emissions from CDPF equipped nonroad engines will contribute only a very small fraction of the total tailpipe PM emissions (less than 0.004 g/bhp-hr). Alternatively, it may be less expensive or more practical for some applications to ensure that the SOF control realized by the CDPF is in excess of 90 percent, thereby allowing for higher engine-out SOF emission levels.

The catalytic materials used on a CDPF to promote soot regeneration and to control SOF emissions are also effective to control NMHC emissions including toxic hydrocarbon emissions. CDPFs designed for operation on low sulfur diesel fuel (i.e., with highly active catalyst technologies) can reduce total hydrocarbon emissions by more than 90 percent.[16] Toxic hydrocarbon emissions are typically reduced in proportion to total hydrocarbon emissions. Table 4.1-1 shows hydrocarbon compound reduction data for two different CDPF technologies.[17]

Table 4.1-1 Polyaromatic Hydrocarbon Reductions with a CDPF

Polyaromatic Hydrocarbon Reductions with Catalyzed Diesel Particulate Filters					
Compound	**Baseline**	**DPF-A**	**DPF-B**	**%Red DPF-A**	**%Red DPF-B**
Napthalene	295	50	0	83%	100%
2-Methylnapthalene	635	108	68	83%	89%
Acenapthalene	40	0.8	1	98%	98%
Acenapthene	46	6.7	11	85%	76%
Fluorene	72	29	12	60%	83%
Phenanthrene	169	33	26	81%	85%
Anthracene	10	1	1	90%	90%
Fluoranthene	7.7	0	2	100%	74%
Pyrene	14	0	2	100%	86%
Benzo(a)anthracene	0.22	0	0.01	100%	95%
Chrysene	0.51	0	0	100%	100%
Benzo(b)fluoranthene	0.26	0	0	100%	100%
Benzo(k)fluoranthene	0.15	0	0	100%	100%
Benzo(e)pyrene	0.26	0	0	100%	100%
Perylene	0.01	0	0	100%	100%
Indeno(123-cd)pyrene	0.13	0	0	100%	100%
Dibenz(ah)anthracene	0.01	0	0	100%	100%
Benzo(ghi)perylene	0.32	0	0	100%	100%

The best means to reduce sulfate emissions from diesel engines is by reducing the sulfur content of diesel fuel and lubricating oils. This is one of the reasons that we have proposed today to limit nonroad diesel fuel sulfur levels to be 15ppm or less. The catalytic material on the CDPF is crucial to ensuring robust regeneration and high SOF oxidation; however, it can also oxidize the sulfate in the exhaust with high efficiency. The result is that the predominant form of PM emissions from CDPF equipped diesel engines is sulfate PM. Even with 15ppm sulfur diesel fuel a CDPF equipped diesel engine can have total PM emissions including sulfate emissions as high as 0.009 g/bhp-hr over some representative operating cycles using conventional diesel engine oils. This level of emissions will allow for compliance with our proposed PM emissions standard of 0.01 g/bhp-hr, and we further believe that there is room for reductions from this level in order to provide engine manufacturers with additional compliance margin. During our 2002 Highway Progress Review, we learned that a number of engine lubricating oil companies are working to reduce the sulfur content in engine lubricating oils. Any reduction in the sulfur level of engine lubricating oils will be beneficial. Similarly, as discussed above, we expect engine manufacturers to reduce engine oil consumption in order to reduce SOF emissions and secondarily to reduce sulfate PM emissions. While we believe that sulfate PM emissions will be the single largest source of the total PM from diesel engines, we believe with the combination of technology, and the appropriate control of engine out PM, that sulfate and total PM emissions will be low enough to allow compliance with a 0.01 g/bhp-hr standard, except in the case of small engines with higher fuel consumption rates as described later in this section.

CDPFs have been shown to be very effective at reducing PM mass by reducing dramatically the soot and SOF portions of diesel PM. In addition, recent data show that they are also very effective at reducing the overall number of emitted particles when operated on low sulfur fuel. Hawker, et. al., found that a CDPF reduced particle count by over 95 percent, including some of the smallest measurable particles (< 50 nm), at most of the tested conditions. The lowest observed efficiency in reducing particle number was 86 percent. No generation of particles by the CDPF was observed under any tested conditions.[18] Kittelson, et al., confirmed that ultrafine particles can be reduced by a factor of ten by oxidizing volatile organics, and by an additional factor of ten by reducing sulfur in the fuel. Catalyzed PM traps efficiently oxidize nearly all of the volatile organic PM precursors (SOF), and the reduction of diesel fuel sulfur levels to 15ppm or less will substantially reduce the number of ultrafine PM emitted from diesel engines. The combination of CDPFs with low sulfur fuel is expected to result in very large reductions in both PM mass and the number of ultrafine particles.

Engine operating conditions have little impact on the particulate trapping efficiency of carbon particles by CDPFs, so the greater than 90 percent efficiency for elemental carbon particulate matter will apply to engine operation within the proposed NTE zone, as well as to the test modes which comprise the steady-state test procedures such as the ISO C1. However, engine operation will affect the CDPF regeneration and oxidation of SO_2 to sulfate PM (i.e., “sulfate-make”). Sulfate-make will reduce the measured PM removal efficiency at some NTE operating conditions and some steady-state modes, even at the proposed 15 ppm fuel sulfur cap. This increased sensitivity to fuel sulfur is caused by the higher temperatures that are found at some of the steady-state modes. High exhaust temperatures promote the oxidation of SO_2 to SO_3 (which then combines with water in the exhaust, forming a hydrated sulfate) across the precious metals found in CDPFs. The sulfate emissions condense in the atmosphere (as well as in the CFR mandated dilution tunnel used for PM testing) forming PM.

Under contract from the California Air Resources Board, two nonroad diesel engines were recently tested for PM emissions performance with the application of a CDPF over a number of transient and steady-state test cycles.[19] The first engine was a 1999 Caterpillar 3408 (480 hp, 18 liter displacement) nonroad diesel engine certified to the Tier 1 standards. The engine was tested with and without a CDPF on 12 ppm sulfur diesel fuel. The transient emission results for this engine are summarized in Table 4.1-2 below. The steady-state emission results are summarized in Table 4.1-3. The test results confirm the excellent PM control performance realized by a CDPF with low sulfur diesel fuel across a wide range of nonroad operating cycles in spite of the relatively high engine-out PM emissions from this Tier 1 engine. We would expect engine-out PM emissions to be lower for production Tier 3 compliant diesel engines that will form the technology baseline for Tier 4 engines meeting today’s proposed standard. The engine demonstrated PM emissions of 0.009 g/bhp-hr on the proposed Nonroad Transient Cycle (NRTC) from an engine-out level of 0.256 g/bhp-hr, a reduction of 0.247 g/bhp-hr. The engine also demonstrated excellent PM performance on the existing steady-state ISO C1 cycle with PM emissions of 0.010 g/bhp-hr from an engine-out level of 0.127, a reduction of 0.107 g/bhp-hr. Thus, this engine would be compliant with the emission standard proposed today for $\geq$75 hp variable speed nonroad engines.

When tested on the proposed optional constant speed variable load cycle (CSVL) (to which this engine would not be subject, under this proposal), the engine-out PM emission levels were 0.407 g/bhp-hr and were reduced to 0.016 g/bhp-hr (a reduction of 0.391 g/bhp-hr) with the addition of the PM filter. As tested, this engine would not be compliant with the proposed optional CSVL standard, but this is not surprising given that this Tier 1 engine was designed for variable speed engine operation and not for single speed operation. We have great confidence given the substantial PM reduction realized in this testing over the proposed CSVL cycle with a CDPF that a properly designed nonroad diesel engine will be able to meet the standard of 0.01 g/bhp-hr.

Table 4.1-2 Transient PM Emissions for a Tier 1 NR Diesel Engine with a CDPF

1999 (Tier 1) Caterpillar 3408 (480hp, 18l)

Test Cycle	PM [g/bhp-hr]		Reduction
	Engine Out	w/ CDPF	%
Proposed Nonroad TransientCycle (NRTC)	0.256	0.009	96%
Proposed Constant Speed Variable Load Cycle (CSVL)	0.407	0.016	96%
On-Highway U.S. FTP Transient Cycle (FTP)	0.239	0.019	92%
Agricultural Tractor Cycle (AGT)	0.181	0.009	95%
Backhoe Loader Cycle (BHL)	0.372	0.022	94%
Crawler Tractor Dozer Cycle (CRT)	0.160	0.014	91%
Composite Excavator Duty Cycle (CEX)	0.079	0.009	88%
Skid Steer Loader Typical No. 1 (SST)	0.307	0.016	95%
Skid Steer Loader Typical No. 2 (SS2)	0.242	0.013	95%
Skid Steer Loader Highly Transient Speed (SSS)	0.242	0.008	97%
Skid Steer Loader Highly Transient Torque (SSQ)	0.351	0.004	99%
Arc Welder Typical No.1 (AWT)	0.510	0.018	96%
Arc Welder Typical No.2 (AW2)	0.589	0.031	95%
Arc Welder Highly Transient Speed (AWS)	0.424	0.019	96%
Rubber-Tired Loader Typical No.1 (RTL)	0.233	0.010	96%
Rubber-Tired Loader Typical No.2 (RT2)	0.236	0.011	96%
Rubber-Tired Loader Highly Transient Speed (RTS)	0.255	0.008	97%
Rubber-Tired Loader Highly Transient Torque (RTQ)	0.294	0.009	97%

Table 4.1-2 also shows results over a large number of additional test cycles developed from real world in-use test data to represent typical operating cycles for different nonroad equipment applications (see Chapter 4.2 of this draft RIA for information on these test cycles). The results show that the CDPF technology is highly effective to control in-use PM emissions over any number of disparate operating conditions. Remembering that the base Tier 1 engine was not designed to meet a transient PM standard, the CDPF emissions demonstrated here show that very low emission levels are possible even when engine-out emissions are exceedingly high (e.g., a reduction of 0.558 g/bhp-hr is demonstrated on the AW2 cycle).

The results summarized in the two tables are indicative of the feasibility of the proposed NTE provisions of this rulemaking. In spite of the Tier 1 baseline of this engine, there are only three test results with emissions higher than the permissible limit for the proposed NTE. The first in Table 4.1-2 shows PM emissions of 0.031 over the AW2 cycle but from a very high baseline level of nearly 0.6 g/bh-hr. We believe that simple improvements to the engine-out PM emissions as needed to comply with the Tier 2 emission standard would reduce these emission below the 0.02 level required by the proposed NTE standard. There are two other test points in Table 4.1-3 which are above the proposed NTE emission level, both at 10 percent engine load. However, both are outside the proposed NTE zone which excludes emissions for engine loads below 30 percent. It is important to note that although the engine would not be constrained to meet the proposed NTE under these conditions, the resulting reductions at both points are still substantial in excess of 96 percent.

Table 4.1-3 Steady-State PM Emissions from a Tier 1 NR Diesel Engine w/ CDPF

1999 (Tier 1) Caterpillar 3408 (480hp, 18l)				
Engine Speed	Engine Load	PM ([g/bhp-hr]		Reduction
%	%	Engine Out	w/ CDPF	%
100	100	0.059	0.010	83%
100	75	0.103	0.009	91%
100	50	0.247	0.012	95%
100	25	0.247	0.000	100%
100	10	0.925	0.031	97%
60	100	0.028	0.011	61%
60	75	0.138	0.009	93%
60	50	0.180	0.010	95%
60	25	0.370	0.007	98%
60	10	0.801	0.018	98%
91	82	0.091	0.006	93%
80	63	0.195	0.008	96%
63	40	0.240	0.008	97%
0	0	--	--	--
	ISO C1 Composite	0.127	0.011	91%

The second engine tested was a prototype engine developed at Southwest Research Institute (SwRI) under contract to EPA.[20] The engine, dubbed Deere Development Engine 4045 (DDE-4045) because the prototype engine was based on a John Deere 4045 production engine, was also tested with a CDPF from a different manufacturer on the same 12 ppm diesel fuel. The engine is very much a prototype and experienced a number of part failures during testing including to the turbocharger actuator. Nevertheless, the transient emission results summarized in Table 4.1-4 and the steady-state results summarized in Table 4.1-5 show that substantial PM reductions are realized on this engine as well. The emission levels on the NRTC and the ISO C1 cycle would be compliant with the proposed PM standard of 0.01 g/bhp-hr once the appropriate rounding convention is applied.[B] It is also interesting to note that the on-highway FTP transient emissions are higher than for either of the proposed nonroad transient tests. This suggests that developing PM compliant engines on the proposed nonroad transient cycles may not be substantially different from developing compliant technologies for on-highway engines.

[B] The rounding procedures in ASTM E29-90 are applied to the emission standard, therefore, the emission results are rounded to the same number of significant digits as the specified standard, i.e., 0.014 g/bhp-hr is rounded to 0.01 g/bhp-hr, while 0.015 g/bhp-hr would be rounded to 0.02 g/bhp-hr.

Table 4.1-4 Transient PM Emissions for a Prototype NR Diesel Engine with a CDPF

EPA Prototype Tier 3 DDE-4045 (108hp, 4.5l)

	PM [g/bhp-hr]		Reduction
Test Cycle	Engine Out	w/ CDPF	%
Proposed Nonroad TransientCycle (NRTC)	0.143	0.013	91%
Proposed Constant Speed Variable Load Cycle (CSVL)	0.218	0.018	92%
On-Highway U.S. FTP Transient Cycle (FTP)	0.185	0.023	88%
Agricultural Tractor Cycle (AGT)	0.134	0.008	94%
Backhoe Loader Cycle (BHL)	0.396	0.021	95%
Crawler Tractor Dozer Cycle (CRT)	0.314	0.008	97%
Composite Excavator Duty Cycle (CEX)	0.176	0.009	95%
Skid Steer Loader Typical No. 1 (SST)	0.288	0.012	96%
Skid Steer Loader Typical No. 2 (SS2)	0.641	0.013	98%
Skid Steer Loader Highly Transient Speed (SSS)	0.298	0.011	96%
Skid Steer Loader Highly Transient Torque (SSQ)	0.536	0.014	97%
Arc Welder Typical No.1 (AWT)	0.290	0.018	94%
Arc Welder Typical No.2 (AW2)	0.349	0.019	95%
Arc Welder Highly Transient Speed (AWS)	0.274	0.019	93%
Rubber-Tired Loader Typical No.1 (RTL)	0.761	0.014	98%
Rubber-Tired Loader Typical No.2 (RT2)	0.603	0.012	98%
Rubber-Tired Loader Highly Transient Speed (RTS)	0.721	0.010	99%
Rubber-Tired Loader Highly Transient Torque (RTQ)	0.725	0.009	99%

As with the results from the Caterpillar engine, the two low-load (10 percent load) steady-state emissions points (see table 4.1-5) have some of the highest brake specific emission rates. These rates are not high enough however to preclude compliance with the steady-state emission cycle, are not within the proposed NTE zone, and still show substantial PM reduction levels.

Table 4.1-5 Steady-State PM Emissions for a Prototype NR Diesel Engine w/CDPF

EPA Prototype Tier 3 DDE-4045 (108hp, 4.5l)

Engine Speed	Engine Load	PM [g/bhp-hr]		Reduction
%	%	Engine Out	w/ CDPF	%
100	100	0.178	0.012	93%
100	75	0.116	0.006	95%
100	50	0.126	0.006	96%
100	25	0.218	0.013	94%
100	10	0.470	0.029	94%
60	100	0.045	0.007	84%
60	75	0.062	0.014	78%
60	50	0.090	0.009	90%
60	25	0.146	0.019	87%
60	10	0.258	0.046	82%
91	82	0.094	0.004	95%
80	63	0.099	0.006	94%
63	40	0.136	0.011	92%
0	0	--	--	--
	ISO C1 Composite	0.129	0.010	92%

The proposed NTE requirement, unlike the proposed nonroad transient cycle (NRTC) or the existing ISO C1 cycle, is not a composite test. In fact, a number of the individual modes within the C1 cycle test fall within the proposed NTE engine control zone. As discussed above, CDPFs are very efficient at capturing elemental carbon PM (up to 99 percent), but sulfate-make under certain operating conditions may exceed the proposed NRTC or C1 standard of 0.01 g/bhp-hr, which is part of the reason the proposed PM NTE standard is greater than the NRTC and C1 PM standards.

The proposed NTE requirements apply not only during standard laboratory conditions, but also during the expanded ambient temperature, humidity, and altitude limits defined in the regulations. We believe the proposed NTE PM standard is technologically feasible across this range of ambient conditions. As discussed above, CDPFs are mechanical filtration devices, and ambient temperature changes will have minimal effect on CDPF performance. Ambient altitude will also have minimal, if any, effects on CDPF filtration efficiencies, and ambient humidity should have no effect on CDPF performance. As discussed above, particulate sulfate make is sensitive to high exhaust gas temperatures, however, at sea-level conditions, the proposed NTE requirements apply up to ambient temperatures which are only 14˚F greater than standard test cell conditions (100˚F under the proposed NTE, versus 86˚F for C1 laboratory conditions). At an altitude of 5,500 feet above sea-level, the proposed NTE applies only up to an ambient temperature within the range of standard laboratory conditions (i.e., 86˚F). These small or non-existent differences in ambient temperature should have little effect on the sulfate make of CDPFs, and as can be seen in tables 4.1-3 and 4.1-5 above, even when tested at an engine operating test mode representative of the highest particulate sulfate generating conditions (peak-torque operation) with 12 ppm sulfur diesel fuel, the results show the engine would easily comply with the PM NTE standard. Based on the available test data and the expected impact of the expanded, but constrained, ambient conditions under which engines must comply with the proposed NTE, we conclude that the proposed PM NTE standard for engines of 75 hp or higher is technologically feasible, provided low sulfur diesel fuel (15 ppm or lower) is available. A discussion of the technical feasibility for engines with rated power lower than 75 hp is given later in this chapter.

4.1.1.3.2 CDPF Regeneration

Diesel particulate filters (DPFs) control diesel PM by capturing the soot portion of PM in a filter media, typically a ceramic wall flow substrate, and then by oxidizing (burning) it in the oxygen-rich atmosphere of diesel exhaust. The SOF portion of diesel PM can be controlled through the addition of catalytic materials to the DPF to form a catalyzed diesel particulate filter (CDPF).[C] The catalytic material is also very effective to promote soot burning. This burning off of collected PM is referred to as "regeneration." In aggregate over an extended period of operation, the PM must be regenerated at a rate equal to or greater that its accumulation rate, or the DPF will clog.

For a non-catalyzed DPF the soot can regenerate only at very high temperatures, in excess of 600˚C, a temperature range which is infrequently realized in normal diesel engine operation (for many engines' exhaust temperatures may never reach 600˚C). With the addition of a catalytic coating to make a CDPF, the temperature necessary to ensure regeneration is decreased significantly to approximately 250˚C, a temperature within the normal operating range for most diesel engines.[21]

However, the catalytic materials that most effectively promote soot and SOF oxidation are significantly impacted by sulfur in diesel fuel. Sulfur both degrades catalyst oxidation efficiency (i.e. poisons the catalyst) and forms sulfate PM. Both catalyst poisoning by sulfur and increases in PM

[C] With regard to gaseous emissions such as NMHCs and CO, the CDPF works in the same manner with similar effectiveness as the DOC (i.e., NMHC and CO emissions are reduced by more than 80 percent).

emissions due to sulfate make influence our decision to limit the sulfur level of diesel fuel to 15 ppm as discussed in greater detail in the discussion below of the need for low sulfur diesel fuel.

Filter regeneration is affected by catalytic materials used to promote oxidation, sulfur in diesel fuel, engine-out soot rates, and exhaust temperatures. At higher exhaust temperatures soot oxidation occurs at a higher rate. Catalytic materials accelerate soot oxidation at a single exhaust temperatures compared to non-catalyst DPFs, but even with catalytic materials increasing the exhaust temperature further accelerates soot oxidation.

Having applied 15 ppm sulfur diesel fuel and the best catalyst technology to promote low temperature oxidation (regeneration), the regeneration balance of soot oxidation equal to or greater than soot accumulation over aggregate operation simplifies to: are the exhaust temperatures high enough on aggregate to oxidize the engine out PM rate?[D] The answer is yes, for most highway applications and many nonroad applications, as demonstrated by the widespread success of retrofit CDPF systems for nonroad equipment and the use of both retrofit and original equipment CDPF systems for on-highway vehicles.[22,23,24] However, it is possible that for some nonroad applications the engine out PM rate may exceed the soot oxidation rate even with low sulfur diesel fuel and the best catalyst technologies. Should this occur, successful regeneration requires that either engine out PM rates be decreased or exhaust temperatures be increased, both feasible strategies. In fact, we expect both to occur as highway based technologies are transferred to nonroad engines. As discussed earlier, engine technologies to lower PM emissions while improving fuel consumption are continuously being developed and refined. As these technologies are applied to nonroad engines driven by both new emission standards and market pressures for better products, engine out PM rates will decrease. Similarly, techniques to raise exhaust temperatures periodically in order to initiate soot oxidation in a PM filter have been developed for on-highway diesel vehicles as typified by the PSA system used on more than 400,000 vehicles in Europe.[25]

During our 2002 Highway Diesel Progress Review, we investigated the plans of on-highway engine manufacturers to use CDPF systems to comply with the HD2007 emission standards for PM. We learned that all diesel engine manufacturers intend to comply through the application of CDPF system technology. We also learned that the manufacturers are developing means to raise the exhaust temperature, if necessary, to ensure that CDPF regeneration occurs.[26] These technologies include modifications to fuel injection strategies, modifications to EGR strategies, and modifications to turbocharger control strategies. These systems are based upon the technologies used by the engine manufacturers to comply with the 2004 on-highway emission standards. In general, the systems anticipated to be used by highway manufacturers to meet the 2004 emission standards are the same technologies that engine manufacturers have indicated to EPA that they will use to comply with the Tier 3 nonroad regulations (e.g., electronic fuel systems).[27] In a manner similar to highway engine manufacturers, we expect nonroad engine manufacturers to adapt their Tier 3 emission control technologies to provide back-up regeneration systems for CDPF technologies in order to comply with the standards we are proposing today. We have estimated costs for such systems in our cost analysis.

[D] If the question was asked, “without 15 ppm sulfur fuel and the best catalyst technology, are the exhaust temperatures high enough on aggregate to oxidize the engine out PM rate?” the answer would be no, for all but a very few nonroad or on-highway diesel engines.

4.1.1.3.3 Current Status of CDPF Technology

More than one emission control manufacturer is developing CDPFs. In field trials, they have demonstrated highly efficient PM control and promising durability. A recent publication documents results from a sample of these field test engines after years of use in real world applications.[28] The sampled CDPFs had on average four years of use covering more than 225,000 miles in applications ranging from city buses to garbage trucks to intercity trains, with some units accumulating more than 360,000 miles. When tested on the US Heavy-Duty Federal Test Procedure (HD FTP), they continued to demonstrate PM reductions in excess of 90 percent.

Another program evaluating CDPFs in the field is the ARCO Emission Control Diesel (EC-D) program.[E] In that program, a technology validation is being run to evaluate EC-D and CDPFs using diesel vehicles operating in southern California. The fuel's performance, impact on engine durability and vehicle performance, and emission characteristics are being evaluated in several fleets in various applications. The program is still ongoing, but interim results have been made available.[29] These interim results have shown that vehicles retrofitted with CDPFs and fueled with EC-D (7.4 ppm sulfur) emitted 91 percent to 99 percent less PM compared to the vehicles fueled with California diesel fuel (121 ppm sulfur) having no exhaust filter equipment. Further, the test vehicles equipped with the CDPFs and fueled with EC-D have operated reliably during the program start-up period and no significant maintenance issues have been reported for the school bus, tanker truck and grocery truck fleets that have been operating for over six months (approximately 50,000 miles).[30]

Even with the relatively mature state of the CDPF technology, progress is still being made to improve catalytic-based soot regeneration technologies and to develop system solutions to ensure that even under the most extreme conditions soot regeneration can be assured. Improvements in catalytic soot oxidation are important because more active soot oxidation can help to improve fuel economy and to ensure robust soot regeneration. A PM filter with a more effective soot oxidation catalyst would be expected to have a lower average soot loading and therefore would be less restrictive to exhaust flow, thus decreasing the pressure drop across the PM filter and leading to better fuel economy. Improved soot oxidation effectiveness will also provide additional assurance that excessive soot loading which could lead to PM filter failure will not occur.

At a recent conference of the Society of Automotive Engineers (SAE) a paper was presented that documented improvements in catalyzed diesel particulate filter system design in order to improve soot oxidation effectiveness. The paper showed that changes in where catalytic materials were coated within a PM filter system (on an upfront flow through catalyst, on the surface of the PM filter or a combination of both) influenced the effectiveness of the catalyst material to promote soot oxidation.[31] This kind of system analysis suggests that there remain opportunities to further improve how diesel particulate filters are designed to promote soot oxidation and that different solutions may be chosen dependent upon expected nonroad equipment operation (expected exhaust temperature history), packaging constraints and cost.

Although highly effective catalytic soot oxidation, enabled by clean diesel fuel (15 ppm S), suggests that PM filters will regenerate passively for most vehicle and many nonroad equipment

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[E] EC-D is a diesel fuel developed recently by ARCO (Atlantic Richfield Company) from typical crude oil using a conventional refining process and having a fuel sulfur content less than 15 ppm.

applications, there remains the possibility that for some conditions active regeneration systems (backup systems) may be desirable. This is perhaps most likely for vehicles which are operated primarily as passenger vehicles (light duty cars and trucks, and some light heavy-duty trucks). For this reason a number of vehicle manufacturers have developed systems to help ensure that PM soot regeneration can occur under all conditions. One example of this is a current production product sold in Europe by PSA/Peugeot. On diesel powered Peugeot 607 passenger cars (a Ford Taurus-sized passenger car) a PM filter system is installed that includes mechanisms for engine-promoted soot oxidation. The vehicle estimates soot loading from a number of parameters including exhaust backpressure and can periodically promote more rapid soot oxidation by injecting additional fuel late in the combustion cycle. This fuel is injected so late in the cycle that it does not contribute to engine power but instead is combusted (oxidized) across an oxidation catalyst in front of the PM filter. The combustion of the fuel across the catalyst increases the exhaust temperature substantially, encouraging rapid soot oxidation. Peugeot has sold more than 400,000 passenger cars with this technology and expects to expand the use of the system across all of its diesel vehicle lines.[32] Other European vehicle manufacturers indicated to EPA during our progress review, that they intend to introduce similar technologies in the near future. They noted that this was not driven by regulation but by customer demand for clean diesel technologies. The fact that manufacturers are introducing PM filter technologies in advance of mandatory regulations suggests that the technology is well developed and mature.

The potential for synergistic benefits to the application of both PM filters and NOx adsorbers was highlighted by EPA in the HD2007 RIA but at that time little was known as to the extent of these synergistic benefits.[33] Toyota has developed a combined diesel particulate filter and NOx adsorber technology dubbed DPNR (Diesel Particulate NOx Reduction). The mechanism for synergistic PM soot regeneration with programmed NOx regeneration was recently documented by Toyota in a SAE publication. The paper showed that active oxygen molecules created both under lean conditions as part of the NOx storage function and under rich conditions created by the NOx regeneration function were effective at promoting soot oxidation at low temperatures.[34] This suggests that the combination of a NOx adsorber catalyst function with a diesel particulate filter can provide a more robust soot regeneration system than a PM filter-only technology.

4.1.1.3.4 CDPF Maintenance

Inorganic solid particles present in diesel exhaust can be captured by diesel particulate filters. Typically these inorganic materials are metals derived from engine oil, diesel fuel or even engine wear. Without a PM filter these materials are normally exhausted from the engine as diesel PM. While the PM filter is effective at capturing inorganic materials it is not typically effective at removing them, since they do not tend to be oxidized into a gaseous state (carbon soot is oxidized to CO_2 which can easily pass through the PM filter walls). Because these inorganic materials are not typically combusted and remain after the bulk of the PM is oxidized from the filter they are typically referred to as ash. While filtering metallic ash from the exhaust is an environmental benefit of the PM filter technology it also creates a maintenance need for the PM filter in order to remove the ash from the filter periodically.

The maintenance function for the removal of ash is relatively straightforward, and itself does not present a technical challenge for the industry. However, both the industry and EPA would like to see ash-related PM filter maintenance reduced as much as possible. EPA has specific guidelines for acceptable maintenance intervals for nonroad diesel engines with CDPFs intended to ensure robust emission control technologies (3,000hrs for engines <175 hp and 4,500hrs for engines ≥175hp). Nonroad engine manufacturers are similarly motivated to improve reliability to minimize end-user maintenance costs. The issue of ash accumulation was raised consistently during our progress review visits with the industry. The industry is investigating a number of ways to address this issue including means to improve ash tolerance and to reduce the amount of ash present in diesel exhaust.

For most current PM filter designs ash accumulates at the end of the inlet passages of the PM filter. As more ash is accumulated, the effective filter size is reduced because the ash fills the end of the passage shortening the effective filter length. One simple approach to address ash is to increase PM filter size in order to tolerate higher levels of ash accumulation. This approach, although effective, is undesirable due to the added cost and size of the resulting PM filter. A number of companies are investigating means to develop PM filter mechanisms which are more ash tolerant. These approaches include concepts to increase storage area within the filter itself and concepts which promote self-cleaning of the filter perhaps driven by engine and vehicle vibrations during normal vehicle operation. It was not clear during our review that these technologies would be able to fully address ash accumulation, but they were indicative of the potential to increase the interval between necessary ash removal maintenance activities.

In addition to concepts to improve ash handling, possibilities exist to decrease the amount of ash present in diesel exhaust. The predominant source of ash in diesel exhaust is inorganic materials contained in engine oil (oil ash). A significant fraction of the ash in engine oil is from additives necessary to control acidification of engine oil due in part to sulfuric acid derived from sulfur in diesel fuel. As the sulfur content of diesel fuel is decreased, the need for acid neutralizing additives in engine oil should also decrease. The concept of an engine oil with less ash content is often referred to as “low-ash oil.” A number of technical programs are ongoing to determine the impact of changes in oil ash content and other characteristics of engine oil on exhaust emission control technologies and engine wear and performance. Historically, as engine technologies have changed (often due to changes in emission regulations) engine oil formulations have also changed. These changes have been accomplished through industry consensus on oil specifications based on defined test protocols. This process of consensus definition has begun to develop engine oils specifications for on-highway diesel engines for the 2007 model year. This engine oil will also be appropriate for application to nonroad diesel engine designed with the same technologies (i.e., an engine oil specification designed for on-highway HD2007 emission technology engines would also be appropriate for use on Tier 4 emission technology engines).

It may also be possible to reduce the ash level in diesel exhaust by reducing oil consumption from diesel engines. Diesel engine manufacturers over the years have reduced engine oil consumption in order to reduce PM emissions and to reduce operating costs for engine owners. Further improvements in oil consumption may be possible in order to reduce ash accumulation rates in PM filters. If oil accumulation rates could be halved and engine oil ash content similarly decreased, the PM filter maintenance interval would be increased fourfold. Current retrofit PM filter ash maintenance intervals can range from 50k miles to more than 200k miles.[35]

4.1.2 NOx Control Technologies

Oxides of nitrogen (NO and NO_2, collectively called NOx) are formed at high temperatures during the diesel combustion process from nitrogen and oxygen present in the intake air. The NOx formation rate is exponentially related to peak cylinder temperatures and is also strongly related to nitrogen and oxygen content (partial pressures). NOx control technologies for diesel engines have focused on reducing emissions by lowering the peak cylinder temperatures and by decreasing the oxygen content of the intake air.

4.1.2.1 In-Cylinder NOx Control Technologies

A number of technologies have been developed to accomplish these objectives including fuel injection timing retard, fuel injection rate control, charge air cooling, exhaust gas recirculation (EGR) and cooled EGR. The use of these technologies can result in significant reductions in NOx emissions, but are limited due to practical and physical constraints of heterogeneous diesel combustion.[36]

A new form of diesel engine combustion, commonly referred to as homogenous diesel combustion or premixed diesel combustion, can give very low NOx emissions over a limited range of diesel engine operation. In the regions of diesel engine operation over which this combustion technology is feasible (light-load conditions), NOx emissions can be reduced enough to comply with the 0.3 g/bhp-hr NOx emission standard that we have proposed today.[37] Some engine manufacturers are today producing engines which utilize this technology over a narrow range of engine operation.[38] Unfortunately, it is not possible today to apply this technology over the full range of diesel engine operation. We do believe that more engine manufacturers will utilize this alternative combustion approach in the limited range over which it is effective, but will have to rely on conventional heterogenous diesel combustion for the bulk of engine operation. See Section 4.1.1.1 for additional discussion of homogenous diesel combustion and PM emission control.

4.1.2.2 Lean NOx Catalyst Technology

Lean NOx catalysts have been under development for some time, and two methods have been developed for using a lean NOx catalyst depending on the level of NOx reduction desired though neither method can produce more than a 30 percent NOx reduction. The “active” lean NOx catalyst injects a reductant that serves to reduce NOx to N_2 and O_2 (typically diesel fuel is used as the reductant). The reductant is introduced upstream of, or into, the catalyst. The presence of the reductant provides locally oxygen poor conditions which allows the NOx emissions to be reduced by the catalyst.

The lean NOx catalyst washcoat incorporates a zeolite catalyst that acts to adsorb hydrocarbons from the exhaust stream. Once adsorbed on the zeolite, the hydrocarbons will oxidize and create a locally oxygen poor region that is more conducive to reducing NOx. To promote hydrocarbon oxidation at lower temperatures, the washcoat can incorporate platinum or other precious metals. The platinum also helps to eliminate the emission of unburned hydrocarbons that can occur if too much reductant is injected, referred to as “hydrocarbon slip.” With platinum, the NOx conversion can take place at the low exhaust temperatures that are typical of diesel engines. However, the presence of the precious metals can lead to production of sulfate PM, as already discussed for PM control technologies.

Active lean NOx catalysts have been shown to provide up to 30 percent NOx reduction under limited steady-state conditions. However, this NOx control is achieved with a fuel economy penalty upwards of 7 percent due to the need to inject fuel into the exhaust stream.[39] NOx reductions over the HD transient FTP are only on the order of 12 percent due to excursions outside the optimum NOx reduction efficiency temperature range for these devices.[40] Consequently, the active lean NOx catalyst does not appear to be capable of enabling the significantly lower NOx emissions required by the proposed NOx standard.

The "passive" lean NOx catalyst uses no reductant injection. Therefore, the passive lean NOx catalyst is even more limited in its ability to reduce NOx because the exhaust gases normally contain very few hydrocarbons. For that reason, today's passive lean NOx catalyst is capable of best steady state NOx reductions of less than 10 percent. Neither approach to lean NOx catalysis listed here can provide the significant NOx reductions necessary for compliance with the proposed Tier 4 standards.

4.1.2.3 NOx Adsorber Technology

NOx emissions from gasoline-powered vehicles are controlled to extremely low levels through the use of the three-way catalyst technology first introduced in the 1970s. Three-way-catalyst technology is very efficient in the stochiometric conditions found in the exhaust of properly controlled gasoline-powered vehicles. Today, an advancement upon this well-developed three-way catalyst technology, the NOx adsorber, has shown that it too can make possible extremely low NOx emissions from lean-burn engines such as diesel engines.[F] The potential of the NOx adsorber catalyst is limited only by its need for careful integration with the engine and engine control system (as was done for three-way catalyst equipped passenger cars in the 1980s and 1990s) and by poisoning of the catalyst from sulfur in the fuel. The Agency set stringent new NOx standards for on-highway diesel engines beginning in 2007 predicated upon the use of the NOx adsorber catalyst enabled by significant reductions in fuel sulfur levels (15 ppm sulfur or less). In today's action, we are proposing similarly stringent NOx emission standards for nonroad engines greater than 75 hp, again using technology enabled by a reduction in fuel sulfur levels.

NOx adsorbers work to control NOx emissions by storing NOx on the surface of the catalyst during the lean engine operation typical of diesel engines. The adsorber then undergoes subsequent brief rich regeneration events where the NOx is released and reduced across precious metal catalysts. The NOx storage period can be as short as 15 seconds and as along as 10 minutes depending upon engine out NOx emission rates and exhaust temperature. A number of methods have been developed to accomplish the necessary brief rich exhaust conditions necessary to regenerate the NOx adsorber technology including late-cycle fuel injection, also called post injection, in exhaust fuel injection, and dual bed technologies with off-line regeneration.[41,42,43] This method for NOx control has been shown to be highly effective when applied to diesel engines but has a number of technical challenges associated with it. Primary among these is sulfur poisoning of the catalyst as described in Section 4.1.2.3.x below.

[F] NOx adsorber catalysts are also called, NOx storage catalysts (NSCs), NOx storage and reduction catalysts (NSRs), and NOx traps.

4.1.2.3.1 How do NOx Adsorbers Work?

The NOx adsorber catalyst is a further development of the three-way catalyst technology developed for gasoline powered vehicles more than twenty years ago. The NOx adsorber enhances the three-way catalyst function through the addition of storage materials on the catalyst surface which can adsorb NOx under oxygen rich conditions. This enhancement means that a NOx adsorber can allow for control of NOx emissions under lean burn (oxygen rich) operating conditions typical of diesel engines.

Three-way catalysts reduce NOx emissions as well as HC and CO emissions (hence the name three-way) by promoting oxidation of HC and CO to water and CO_2 using the oxidation potential of the NOx pollutant, and, in the process, reducing the NOx emissions to atomic nitrogen, N_2. Said another way, three-way catalysts work with exhaust conditions where the net oxidizing and reducing chemistry of the exhaust is approximately equal, allowing the catalyst to promote complete oxidation/reduction reactions to the desired exhaust components, carbon dioxide (CO_2), water (H_2O) and nitrogen (N_2). The oxidizing potential in the exhaust comes from NOx emissions and some oxygen (O_2) which is not consumed during combustion. The reducing potential in the exhaust comes from HC and CO emissions, which represent products of incomplete combustion. Operation of the engine to ensure that the oxidizing and reducing potential of the combustion and exhaust conditions is precisely balanced is referred to as stoichiometric engine operation.

If the exhaust chemistry varies from stoichiometric conditions emission control is decreased. If the exhaust chemistry is net “fuel rich,” meaning there is an excess of HC and CO emissions in comparison to the oxidation potential of the NOx and O_2 present in the exhaust, the excess HC and CO pollutants are emitted from the engine. Conversely, if the exhaust chemistry is net “oxygen rich” (lean burn), meaning there is an excess of NOx and O_2 in comparison to the reducing potential of the HC and CO present in the exhaust, the excess NOx pollutants are emitted from the engine. It is this oxygen rich operating condition that typifies diesel engine operation. Because of this, diesel engines equipped with three-way catalysts (or simpler oxidation catalysts) have very low HC and CO emissions while NOx (and O_2) emissions remain almost unchanged from the high engine out levels. For this reason, when diesel engines are equipped with catalysts (diesel oxidation catalysts (DOCs)) they have HC and CO emissions that are typically lower, but have NOx emissions that are an order of magnitude higher, than for gasoline engines equipped with three-way catalysts.

The NOx adsorber catalyst works to overcome this situation by storing NOx emissions when the exhaust conditions are oxygen rich. Unfortunately the storage capacity of the NOx adsorber is limited, requiring that the stored NOx be periodically purged from the storage component. If the exhaust chemistry is controlled such that when the stored NOx emissions are released the net exhaust chemistry is at stoichiometric or net fuel rich conditions, then the three-way catalyst portion of the catalyst can reduce the NOx emissions in the same way as for a gasoline three-way catalyst equipped engine. Simply put, the NOx adsorber works to control NOx emissions by storing NOx on the catalyst surface under lean burn conditions typical of diesel engines and then by reducing the NOx emissions with a three-way catalyst function by periodically operating under stoichiometric or fuel rich conditions.

The NOx storage process can be further broken down into two steps. First the NO in the exhaust is oxidized to NO_2 across an oxidation promoting catalyst, typically platinum. Then the NO_2 is further oxidized and stored on the surface of the catalyst as a metallic nitrate (MNO_3). The storage components are typically alkali or alkaline earth metals that can form stable metallic nitrates. The most common storage component is barium carbonate ($BaCO_3$) which can store NO_2 as barium nitrate ($Ba(NO_3)_2$) while releasing CO_2. In order for the NOx storage function to work, the NOx must be oxidized to NO_2 prior to storage and a storage site must be available (the device cannot be "full"). During this oxygen rich portion of operation, NOx is stored while HC and CO emissions are oxidized across the three-way catalyst components by oxygen in the exhaust. This can result in near zero emissions of NOx, HCs, and CO under the net oxygen rich operating conditions typical of diesel engines.

The NOx adsorber releases and reduces NOx emissions under fuel rich operating conditions through a similar two step process, referred to here as NOx adsorber regeneration. The metallic nitrate becomes unstable under net fuel rich operating conditions, decomposing and releasing the stored NOx. Then the NOx is reduced by reducing agents in the exhaust (CO and HCs) across a three-way catalyst system, typically containing platinum and rhodium. Typically, this NOx regeneration step occurs at a significantly faster rate than the period of lean NOx storage such that the fuel rich operation constitutes only a small fraction of the total operating time. Since this release and reduction step, NOx adsorber regeneration, occurs under net fuel rich operating conditions, NOx emissions can be almost completely eliminated. But for some of the HC and CO emissions, "slip"(failure to remove all of the HC and CO) may occur during this process. The HC and CO slip can be controlled with a downstream "clean-up" catalyst that promotes their oxidation or potentially by controlling the exhaust constituents such that the excess amount of the HC and CO pollutants at the fuel rich operating condition is as low as possible, that is, as close to stoichiometric conditions as possible.

The difference between stoichiometric three-way catalyst function and the newly developed NOx adsorber technology can be summarized as follows. Stoichiometric three-way catalysts work to reduce NOx, HCs and CO by maintaining a careful balance between oxidizing (NOx and O_2) and reducing (HCs and CO) constituents and then promoting their mutual destruction across the catalyst on a continuous basis. The newly developed NOx adsorber technology works to reduce the pollutants by balancing the oxidation and reduction chemistry on a discontinuous basis, alternating between net oxygen rich and net fuel rich operation in order to control the pollutants. This approach allows lean-burn engines (oxygen rich operating), like diesel engines, to operate under their normal operating mode most of the time, provided that they can periodically switch and operate such that the exhaust conditions are net fuel rich for brief periods. If the engine/emission control system can be made to operate in this manner, NOx adsorbers offer the potential to employ the highly effective three-way catalyst chemistry to lean burn engines.

4.1.2.3.2 NOx Adsorber Regeneration Mechanisms

NOx adsorbers work to control NOx emissions by storing the NOx pollutants on the catalyst surface during oxygen rich engine operation (lean burn engine operation) and then by periodically releasing and reducing the NOx emissions under fuel rich exhaust conditions. This approach to controlling NOx emissions can work for a diesel engine provided that the engine and emission control system can be designed to work in concert, with relatively long periods of oxygen rich operation (typical diesel engine operation) followed by brief periods of fuel rich exhaust operation. The ability to control the NOx emissions in this manner is the production basis for lean burn NOx emission control in stationary power systems and for lean burn gasoline engines. As outlined below we believe that there are several approaches to accomplish the required periodic operation on a diesel engine.

The most frequently mentioned approach for controlling the exhaust chemistry of a diesel engine is through in-cylinder changes to the combustion process. This approach roughly mimics the way in which lean-burn gasoline engines function with NOx adsorbers. That is the engine itself changes in operation periodically between "normal" lean burn (oxygen rich) combustion and stoichiometric or even fuel rich combustion in order to promote NOx control with the NOx adsorber catalyst. For diesel engines this approach typically requires the use of common rail fuel systems which allow for multiple fuel injection events along with an air handling system which includes exhaust gas recirculation (EGR).

The normal lean burn engine operation can last from as little time as 15 seconds to more than three minutes as the exhaust NOx emissions are stored on the surface of the NOx adsorber catalyst. The period of fuel lean, oxygen rich, operation is determined by the NOx emission rate from the engine and the storage capacity of the NOx adsorber. Once the NOx adsorber catalyst is full (once an unacceptable amount of NOx is slipping through the catalyst without storage) the engine must switch to fuel rich operation in order to regenerate the NOx adsorber.

The engine typically changes to fuel rich operation by increasing the EGR rate, by throttling the fresh air intake, and by introducing an additional fuel injection event late in the combustion cycle. The increased EGR rate works to decrease the oxygen content of the intake air by displacing fresh air that has a high oxygen content with exhaust gases that have a much lower oxygen content. Intake air throttling further decreases the amount of fresh air in the intake gases again lowering the amount of oxygen entering the combustion chamber. The combination of these first two steps serves to lower the oxygen concentration in the combustion chamber, decreasing the amount of fuel required in order to reach a fuel rich condition. The fuel is metered then into the combustion chamber in two steps under this mode of operation. The first, or primary, injection event meters a precise amount of fuel in order to deliver the amount of torque (energy) required by the operator demand (accelerator pedal input). The second injection event is designed to meter the amount of fuel necessary in order to achieve a net fuel rich operating condition. That is, the primary plus secondary injection events introduce an excess of fuel when compared to the amount of oxygen in the combustion chamber. The secondary injection event occurs very late in the combustion cycle so that no torque is derived from its introduction. This is necessary so that the switching between the normal lean burn operation and this periodic fuel rich operation is transparent to the user.

Additional ECM capability will be necessary to monitor the NOx adsorber and determine when the NOx regeneration events are necessary. This could be done in a variety of ways, though they fall into two general categories: predictive and reactive. The predictive method would estimate or measure the NOx flow into the adsorber in conjunction with the predicted adsorber performance to determine when the adsorber is near capacity. Then, upon entering optimal engine operating conditions, a NOx regeneration would be performed. This particular step is similar to an on-board diagnostic (OBD) algorithm waiting for proper conditions to perform a functionality check. During the NOx regeneration, sensors would determine how accurately the predictive algorithm performed, and adjust it accordingly. The reactive method is envisioned to monitor NOx downstream of the NOx adsorber and, if NOx slippage is detected, a regeneration event would be triggered. This method is dependent on good NOx sensor technology. This method would also depend on the ability to regenerate under any given engine operating condition, since the algorithm would be reacting to indications that the adsorber had reached its NOx storage capacity. In either case, we believe these algorithms are not far removed from the systems that will be used by nonroad manufacturers to comply with the Tier 3 emission standards and will be virtually identical to the systems used by on-highway manufacturers to comply with the HD2007 emission regulations. When used in combination with the sophisticated control systems that will be available, we expect that NOx regeneration events can be seamlessly integrated into engine operation such that the driver or equipment operator may not be aware that the events are taking place.

Using this approach of periodic switching between normal lean burn operation and brief periods of fuel rich operation all accomplished within the combustion chamber of a diesel engine is one way in which an emission control system for a diesel engine can be optimized to work with the NOx adsorber catalyst. This approach requires no new engine hardware beyond the air handling and advanced common rail fuel systems that many advanced diesel engines will have already applied in order to meet the Tier 3 NOx standard. For this reason an in-cylinder approach is likely to appeal to engine manufacturers for product lines where initial purchase cost or package size is the most important factor in determining engine purchases.

Another approach to accomplish the NOx adsorber regeneration is through the use of a so called "dual-bed" or "multiple-bed" NOx adsorber catalyst system. Such a system is designed so that the exhaust flow can be partitioned and routed through two or more catalyst "beds" which operate in parallel. Multiple-bed NOx adsorber catalysts restrict exhaust flow to part of the catalyst during its regeneration. By doing so, only a portion of the exhaust flow need be made rich, reducing dramatically the amount of oxygen needing to be depleted and thus the fuel required to be injected in order to generate a rich exhaust stream. One simple example of a multiple bed NOx adsorber is the dual-bed system in Figure 4.1-1. In this example, the top half of the adsorption catalyst system is regenerating under a low exhaust flow condition (exhaust control valve nearly closed), while the remainder of the exhaust flow is bypassed to a lower half of the system. A system of this type would have the following characteristics:

- Half of the system would operate with a major flow in an "adsorption mode", where most of the exhaust is well lean of stoichiometric ($\lambda > 1$ or $>>1$, typical diesel exhaust), NO is converted to NO_2 over a Pt-catalyst, and stored as a metallic nitrate within the NOx adsorbent material.[G]

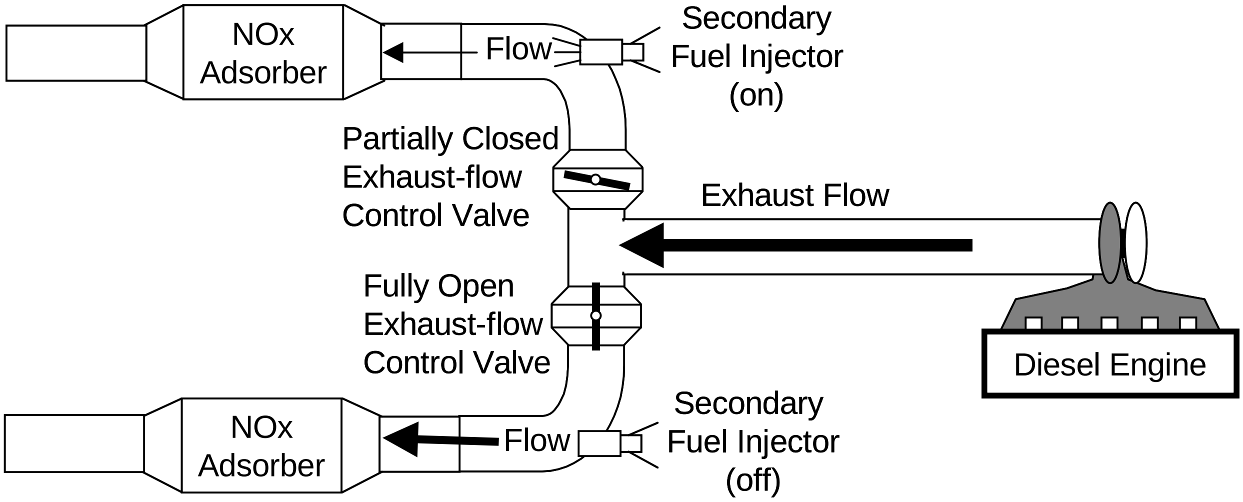
- The other half of the system would have its exhaust flow restricted to just a small fraction (~5 percent) of the total flow and would operate in a regeneration mode.
  - While the flow is restricted for regeneration, a small quantity of fuel is sprayed into the regenerating exhaust flow at the beginning of the regeneration event.
  - The fuel is oxidized by the oxygen in the exhaust until sufficient oxygen is depleted for the stored NOx to be released. This occurs at exhaust conditions of $\lambda \leq 1$.
  - At these conditions, NOx can also be very efficiently reduced to N_2 and O_2 over a precious metal catalyst.

[G] A condition of $\lambda = 1$ means that there are precisely the needed quantity of reactants for complete reaction at equilibrium. $\lambda < 1$ means that there is insufficient oxygen, $\lambda > 1$ means that there is excess oxygen.

- At the completion of regeneration, the majority of the flow can then be reintroduced into the regenerated half of the system by opening the flow control valve.

- Simultaneously, flow is restricted to the other half of the system to allow it to regenerate.

Figure 4.1-1
Schematic Representation of the Operation of a Dual-Bed NOx Adsorption Catalyst



Although the schematic shows two separate systems, the diversion of exhaust flow can occur within a single catalyst housing, and with a single catalyst monolith. There may also be advantages to using more than one partition for the NOx adsorber system such as the use of multiple beds allows desulfation of one bed while normal NOx adsorption and regeneration events occur in other beds.

The NOx adsorber performance can be enhanced by incorporating a catalyzed diesel particulate filter (CDPF) into the system. A number of synergies exist between NOx adsorber systems and CDPFs. Both systems rely on conversion of NO to NO_2 over a Pt catalyst for part of their functioning. Partial oxidation reforming of diesel fuel to hydrogen and CO over a Pt-catalyst has been demonstrated for fuel-cell applications. A similar reaction to reform the fuel upstream of the NOx adsorber during regeneration would provide a more reactive reductant for desorption and reduction of NOx. Heavier fuel hydrocarbons are known to inhibit NOx reduction on the NOx adsorption catalyst since competitive adsorption by hydrocarbons on the precious metal sites inhibits NOx reduction during adsorber regeneration.[44] Partial oxidation of the secondary fuel injected into the exhaust during regeneration could lead to sooting of the fuel. Using a CDPF upstream of the NOx adsorber, but downstream of the secondary fuel injection, allows partial oxidation of the fuel hydrocarbons to occur over the Pt catalyst on the surface of the CDPF. The wall-flow design of the CDPF efficiently captures any soot formed during partial oxidation of the fuel injected into the exhaust, preventing any increase in soot emissions. The partial oxidation reaction over the CDPF is exothermic, which could be used increase the rate of temperature rise for the NOx adsorber catalyst after cold starts, similar to the use of light-off catalysts with cascade three-way catalyst systems.[45]

4.1.2.3.3 How Efficient are Diesel NOx Adsorbers?

Research into applying the NOx adsorber catalyst to diesel exhaust is only a few years old but benefits from the larger body of experience with stationary power sources and with lean burn gasoline systems. In simplest terms the question is how well does the NOx adsorber store NOx under normal lean burn diesel engine operation, and then how well does the control system perform the NOx regeneration function. Both of these functions are affected by the temperature of the exhaust and of the catalyst surface. For this reason efficiency is often discussed as a function of exhaust temperature under steady-state conditions. This is the approach used in this section and is extended in 4.1.3.1.2 below to predict the effectiveness of the NOx adsorber technology on the proposed nonroad test cycles. The potential for both NOx storage and reduction to operate at very high efficiencies can be realized through careful emission control system design as described below.

The NOx storage function consists of oxidation of NO to NO_2 and then storage of the NOx as a metallic nitrate on the catalyst surface. The effectiveness of the catalyst at accomplishing these tasks is dependent upon exhaust temperature, catalyst temperature, precious metal dispersion, NO storage volume, and transport time (mass flow rates through the catalyst). Taken as a whole these factors determine how effective a NOx adsorber based control system can store NOx under lean burn diesel engine operation.

Catalyst and exhaust temperature are important because the rate at which the desirable chemical reactions occur is a function of the local temperature where the reaction occurs. The reaction rate for NO to NO_2 oxidation and for NOx storage increases with increasing temperature. Beginning at temperatures as low as 100˚C NO oxidation to NO_2 can be promoted across a platinum catalyst at a rate high enough to allow for NOx storage to occur. Below 100˚C the reaction can still occur (as it does in the atmosphere); however, the reaction rate is so slow as to make NOx storage ineffective below this temperature in a mobile source application. At higher exhaust temperatures, above 400˚C, two additional mechanisms affect the ability of the NOx adsorber to store NOx. First the NO to NO_2 reaction products are determined by an equilibrium reaction which favors NO rather than NO_2. That is across the oxidation catalyst, NO is oxidizing to form NO_2 and NO_2 is decaying to form NO at a rate which favors a larger fraction of the gas being NO rather than NO_2. As this is an equilibrium reaction when the NO_2 is removed from the gas stream by storage on the catalyst surface, the NOx gases quickly "re-equilibrate" forming more NO_2. This removal of NO_2 from the gas stream and the rapid oxidation of NO to NO_2 means that in spite of the NO_2 fraction of the NOx gases in the catalyst being low at elevated conditions (30 percent at 400˚C) the storage of NOx can continue to occur with high efficiencies, near 100 percent.

Unfortunately, the other limitation of high temperature operation is not so easily overcome. The metallic nitrates that are formed on the catalyst surface and that serve to store the NOx emissions under fuel lean operating conditions can become unstable at elevated temperatures. That is, the metallic nitrates thermally decompose releasing the stored NOx under lean operating conditions allowing the NOx to exit the exhaust system "untreated." The temperature at which the storage metals begin to thermally release the stored NOx emissions varies dependent upon the storage metal or metals used, the relative ratio of the storage metals, and the washcoat design. Changes to catalyst formulations can change the upper temperature threshold for thermal NOx desorption by as much as 100˚C.[46] Thermal stability is the primary factor determining the NOx control efficiency of the NOx adsorber at temperatures higher than 400-500˚C. NOx adsorber catalyst developers are continuing to work to improve this aspect of NOx adsorber performance, and as documented in EPA’s 2002 Highway Progress Review improving temperature performance is being realized.

The NOx adsorber catalyst releases stored NOx emissions under fuel rich operating conditions and then reduces the NOx over a three-way catalyst function. While the NOx storage function determines the NOx control efficiency during lean operation, it is the NOx release and reduction function that determines the NOx control efficiency during NOx regeneration. Since NOx storage can approach near 100 percent effectiveness for much of the temperature range of the diesel engine, the NOx reduction function often determines the overall NOx control efficiency.

NOx release can occur under relatively cool exhaust temperatures even below 200˚C for current NOx adsorber formulations. Unfortunately, the three-way NOx reduction function is not operative at such cool exhaust temperatures. The lowest temperature at which a chemical reaction is promoted at a defined efficiency (often 50 percent) is referred to as the “light-off” temperature. The 80 percent light-off temperature for the three-way catalytic NOx reduction function of current NOx adsorbers is between 200˚C and 250˚C. Therefore, even though NOx storage and release can occur at cooler temperatures, NOx control is limited under steady-state conditions to temperatures greater than this light-off temperature.

Under transient operation however, NOx control can be accomplished at temperatures below this NOx reduction light-off temperature provided that the period of operation at the lower temperature is preceded by operation at higher temperatures and provided that the low temperature operation does not continue for an extended period. This NOx control is possible due to two characteristics of the system specific to transient operation. First, NOx control can be continued below the light-off temperature because storage can continue below that temperature. If the exhaust temperature again rises above the NOx reduction light-off temperature before the NOx adsorber storage function is full, the NOx reduction can then precede at high efficiency. Said another way, if the excursions to very low temperatures are brief enough, NOx storage can proceed under this mode of operation, followed by NOx reduction when the exhaust temperatures are above the light-off temperature. Although this sounds like a limited benefit because NOx storage volume is limited, in fact it can be significant, because the NOx emission rate from the engine is low at low temperatures. While the NOx storage rate may be limited such that at high load conditions the lean NOx storage period would be as short as 30 seconds, at the very low NOx rates typical of low temperature operation (operation below the NOx reduction light-off temperature) this storage period can increase dramatically. This is due to the NOx mass flow rate from the engine changing dramatically between idle conditions and full load conditions. The period of lean NOx storage would be expected to increase in inverse proportion to the NOx emission rate from the engine. Therefore, the period of NOx storage under light load conditions could likewise be expected to increase dramatically as well.

Transient operation can further allow for NOx control below the NOx reduction light-off temperature due to the thermal inertia of the emission control system itself. The thermal inertia of the emission control system can work to warm the exhaust gases to a local temperature high enough to promote the NOx reduction reaction even though the inlet exhaust temperatures are below the light-off temperature for the catalyst.

The combination of these two effects was observed during testing of NOx adsorbers at NVFEL, especially with regards to NOx control under idle conditions. It was observed that when idle conditions followed loaded operation, for example when cooling the engine down after a completing an emission test, that the NOx emissions were effectively zero (below background levels) for extended periods of idle operation (for more than 10 minutes). Additionally it was discovered that the stored NOx could be released and reduced in this operating mode even though the exhaust temperatures were well below 250˚C provided that the regeneration event was triggered within the first 10 minutes of idle operation (before the catalyst temperature decreased significantly). However, if the idle mode was continued for extended periods (longer than 15 minutes) NOx control eventually diminished. The loss of NOx control at extended idle conditions appeared to be due to the inability to reduce the stored NOx leading to high NOx emissions during NOx regeneration cycles.

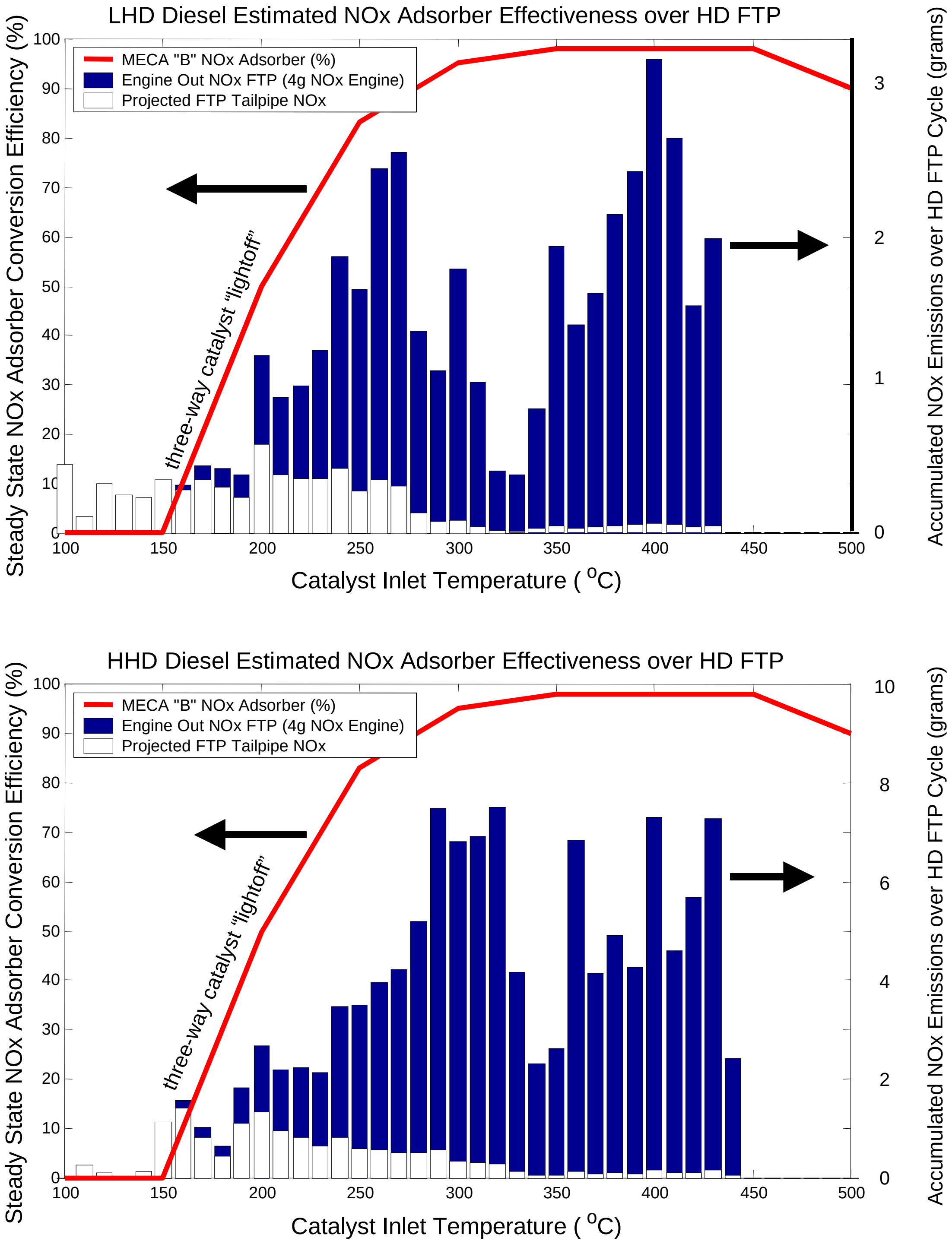
NOx control efficiency with the NOx adsorber technology under steady-state operating conditions can be seen to be limited by the light-off temperature threshold of the three-way catalyst NOx reduction function. Further, a mechanism for extending control below this temperature is described for transient operation and is observed in testing of NOx adsorber based catalyst systems. Additionally, as described later in this section, new combustion strategies such as Toyota’s low temperature combustion technology can raise exhaust temperatures at low loads to promote improved NOx performance with a NOx adsorber catalyst.

Overall, NOx adsorber efficiency reflects the composite effectiveness of the NOx adsorber in storing, releasing and reducing NOx over repeated lean/rich cycles. As detailed above, exhaust temperatures play a critical role in determining the relative effectiveness of each of these catalyst functions. These limits on the individual catalyst functions can explain the observed overall NOx control efficiency of the NOx adsorber, and can be used to guide future research to improve overall NOx adsorber efficiency and the design of an integrated NOx emission control system.

At low exhaust temperatures overall NOx control is limited by the light-off temperature threshold of the three-way NOx reduction function in the range from 200˚C to 250˚C. At high temperatures (above 400˚ to 500˚C) overall NOx control is limited by the thermal stability of the NOx storage function. For exhaust temperatures between these two extremes NOx control can occur at virtually 100 percent effectiveness.

The ability of the complete system including the engine and the emission control system to control NOx emissions consistently well in excess of 90 percent is therefore dependent upon the careful management of temperatures within the system. Figure 4.1-2 provides a pictural representation of these constraints and indicates how well a diesel engine can match the capabilities of a NOx adsorber-based NOx control system. The figure shows accumulated NOx emission (grams) over the on-highway heavy-duty FTP test for both a light heavy-duty (LHD) and a heavy heavy-duty (HHD) engine. The engine-out NOx emissions are shown as the dark bars on the graphs. The accumulated NOx emissions shown here, divided by the integrated work over the test cycle gives a NOx emission rate of 4 g/bhp-hr (the 1998 on-highway HD emission standard) for each of these engines. Also shown on the graph as a solid line is the steady-state NOx conversion efficiency for a NOx adsorber, MECA “B”, used in testing at NVFEL (see Section 4.1.2.3.5.2 below for more details on testing at NVFEL). The line has been annotated to show the constraint under low temperature operation (three-way catalyst light-off). The white bars on the graph represent an estimate of the tailpipe NOx emissions that could be realized from the application of the NOx adsorber based upon the steady-state efficiency curve for adsorber MECA “B”. These estimated tailpipe emissions are highest in the temperature range below 250˚C even though the engine out NOx emissions are the lowest in this region. This is due to the light-off temperature threshold for the NOx three-way reduction function.

Figure 4.1-2
NOx Adsorber Efficiency Characteristics versus Exhaust Temperature



Since the conversion efficiencies are based upon steady-state operation, it is likely that the low temperature performance could be better than estimated here due to catalyst's ability to store the NOx emissions at these low temperatures and then to reduce them when transient operation raises the exhaust temperatures above the three-way light-off temperature. This assertion provides one explanation for differences noted between this approximation to the FTP NOx efficiency for the LHD engine shown in Figure 4.1-2 above and actual NOx adsorber efficiency demonstrated with this engine in the NVFEL test program. Based upon the figure above (using the steady-state conversion estimate) the NOx adsorber catalyst should have provided less than an 84 percent reduction in NOx emissions over the FTP. However, testing at NVFEL (detailed in Section 4.1.2.3.5) has demonstrated a greater than 90 percent reduction in NOx emissions with this same engine and catalyst pair without significant optimization of the system. Clearly then, steady-state NOx adsorber performance estimates can underestimate the real NOx reductions realized in transient vehicle operation. Nevertheless, we have used this approach as a screening analysis to predict performance for nonroad engines equipped with NOx adsorber catalysts in Section 4.1.3.1.2 below.

The tailpipe NOx emissions are the lowest in the range from 250˚C to 450˚C, even though this is where the majority of the engine out NOx emissions are created, because of the high overall NOx reduction efficiency of the NOx adsorber system under these conditions. At temperatures above 500˚C the NOx conversion efficiency of the NOx adsorber can be seen to decrease.

Figure 4.1-2 shows that the temperature window of a current technology NOx adsorber catalyst is well matched to the exhaust temperature profiles of a light heavy-duty and a heavy heavy-duty diesel engine operated over the heavy-duty FTP driving cycle. The discussion in 4.1.3.1.2 below shows similarly that the proposed nonroad transient test cycle (NRTC) is also well matched to the performance of the NOx adsorber catalyst. Testing at NVFEL on the same engine operated over a wide range of steady-state points, shows that even for extended high load operation, as typified by the 100 percent load test points in the test, NOx conversion efficiencies remained near or above 90 percent (See discussion of the NVFEL test program in Section 4.1.2.3.5, below).

The discussion above makes it clear that when the engine and NOx adsorber-based emission control system are well matched, NOx reductions can be far in excess of 90 percent. Conversely, it can be inferred that if exhaust temperatures are well in excess of 500˚C or well below 200˚C for significant periods of engine operation then NOx control efficiency may be reduced. Researchers are developing and testing new NOx adsorber formulations designed to increase the high temperature stability of the NOx adsorber and to therefore widen this window of operation.[47]

How effective are NOx adsorbers for cold start emissions?

In addition to broadening the catalyst temperature window, the exhaust temperature from the diesel engine can be managed to align with the temperature window of the catalyst.

The steady-state analysis discussed above is based on steady-state emission results (i.e., after exhaust temperatures have stabilized), but the proposed NRTC also includes a cold-start test where the catalyst initial temperature will be at ambient conditions. The complete proposed NRTC test sequence will include both a cold start emission test and a hot start emission test as described more fully in 4.2. The NRTC emission level for the engine is determined by weighting the cold-start emissions by 1/10 (10 percent), and weighting the hot-start emission results by 9/10 (90 percent).

Historically, for on-highway heavy-duty diesel engines that are similar to current technology nonroad diesel engines not equipped with an exhaust emission control device, the cold-start and hot-start emissions have been nearly identical. However, with the application of exhaust emission control devices, such as a NOx adsorber, the cold-start test will become a design challenge for on-highway diesel engine manufacturers and, with this proposal, for nonroad diesel engine manufacturers, just as it has been a design challenge for light-duty gasoline vehicle manufacturers for more than 20 years. As discussed above, NOx adsorbers do have optimal temperature operating windows, and thus will represent a design challenge.

Manufacturers have a number of tools available to them to overcome this challenge:

- The volume, shape, and substrate material have a significant effect on the warm-up time of a NOx adsorber (just as they do for a light-duty three-way catalysts). Manufactures will optimize the make-up of the adsorber for best light-off characteristics, such as the thin-walled ceramic monolith catalysts typical of modern low emission light-duty gasoline applications.

- The packaging of the exhaust emission control devices, including the use of insulating material and air-gap exhaust systems, will also decrease light-off time, and we expect manufacturers to explore those opportunities.

- The location of the adsorber, with respect to it’s proximity to the exhaust manifold, will have a significant impact on the light-off characteristics.

- As discussed above, NOx adsorbers have the ability to store NOx at temperatures much less than the three-way catalyst function temperature operating window, on the order of 100˚C. This is unlike the performance of light-duty gasoline catalysts, and it would allow the NOx adsorber to store NOx for some period of time prior to the light-off time of the three-way function of its catalyst, resulting in an overall lower effective temperature for the device.

These first four tools available to manufacturers all deal with system design opportunities to improve the cold-start performance of the NOx adsorber system. In addition, manufactures have a number of active tools which can be used to enhance the cold-start performance of the system all based on technologies which may be used to comply with the Tier 3 emission standards (i.e., technologies which will form the baseline for engines meeting the proposed Tier 4 standards). These include the use of engine start-up routines which have a primary purpose of adding heat to the exhaust to enhance NOx adsorber light-off. For example:

- retarded injection timing;

- intake air throttling;

- post-injection addition of fuel; or

- or increasing back-pressure with an exhaust brake or a VGT system.

We anticipate manufacturers will explore all of these tools in order to choose the best combination necessary to minimize light-off time and improve the cold-start NRTC performance.

On-highway manufacturers must overcome this same challenge in order to comply with the HD2007 emissions standards some number of years before these proposed nonroad emission standards go into effect. Additionally, on-highway manufacturers must do this with a higher cold start weighting of 1/7 rather than 1/10 as proposed today for nonroad engines. This means that on-highway engine manufacturers must have lower cold start emissions relative to their hot start emissions than will nonroad engine manufacturers having to meet our proposed Tier 4 standards. Therefore, we believe that the technologies we expect on-highway engine manufacturers to use for compliance (i.e., the technologies delineated above) for the 2007 standards will be more than capable of being applied to nonroad diesel engines in order to comply with the proposed Tier 4 NRTC including the cold start test.

One light-duty passenger car manufacturer, Toyota, has already demonstrated such an approach to comply with light-duty cold start requirements. Toyota has shown with its low temperature combustion technology one mechanism for raising exhaust temperatures even at extremely low load conditions. The approach, called Low Temperature Combustion (LTC), increases exhaust temperatures at low load conditions by more than 50˚C while decreasing NOx emissions engine out.[48] As a result, exhaust temperature are increased into the region for effective NOx adsorber operation even at light loads. The technologies that Toyota uses to accomplish LTC, cooled EGR and advanced common rail fuel systems, are similar to the systems that we expect many nonroad engine manufacturers will use to comply with the Tier 3 standards.

How effective are NOx adsorbers over the proposed NTE?

We are proposing an NTE standard for nonroad Tier 4 engines that replicates the provisions for on-highway diesel trucks. A complete discussion of that proposal can be found in chapter 4.3. In short, the proposal would set an NTE emissions limit that is 1.5 times the NRTC emissions limit over a broad range of engine operating conditions. As discussed below, a 90 percent NOx reduction is technologically feasible across the range of engine operating conditions and ambient conditions subject to the proposed NTE standards. Also, as discussed below, some modifications to the proposed NTE provisions to address technical issues which arise from the application of advanced NOx catalyst systems were included in the HD2007 standards and are carried over into this proposal.

Section 4.1.2.3.5.2 contains a description of the ongoing NOx adsorber evaluation test program run by our EPA laboratory. Included in that section is test data on four different NOx adsorbers for which extensive steady-state mapping was performed in order to calculate various steady-state emission levels (See Figures 4.1-10 through 4.1-13). Several of the test modes presented in these figure are not within the proposed NTE NOx control zone, and would not be subject to the proposed NTE standard. The following modes listed in these four figures are within the proposed NTE NOx control zone, EPA modes 6 - 13, 15, 17, 19, 20. For all of the adsorbers, efficiencies of 90 percent or greater were achieved across the majority of the proposed NTE zone. The region of the proposed NTE zone for which efficiencies less than 90 percent were achieved were concentrated on or near the torque curve (EPA modes 8, 9, 15 and 17) with the exception of Adsorber D, for which EPA modes 6 and 7 achieved 87 percent and 89 percent NOx reduction respectively. However, Adsorber D was able to achieve NOx reductions greater than 90 percent along the torque curve. The test modes along the torque curve represent the highest exhaust gas temperature conditions for this test engine, on the order of 500˚C. Exhaust temperatures of 500˚C are near the current upper temperature limit of the peak NOx reduction efficiency range for NOx adsorbers, therefore it is not unexpected that the NOx reductions along the torque curve for the test engine are not as high as in other regions of the proposed NTE zone. We would expect manufacturers to choose a NOx adsorber formulation which matches the exhaust gas temperature operating range of the engine. In addition, the steady-state mode data in figures 4.1-10 through 4.1-13 were collected under stabilized conditions. In reality, actual in-use operation of a heavy-duty diesel vehicle would likely not see periods of sustained operation along the torque curve, and therefore the likelihood the NOx adsorber bed itself would achieve temperatures in excess of 500˚C would be diminished. Regardless, as observed in our ongoing diesel progress review and documented in the 2002 diesel progress report, catalyst developers are realizing incremental improvements in the high temperature NOx reduction capabilities of NOx adsorbers through improvements in NOx adsorber formulations.[49,50,51] As discussed above, only small improvements in the current characteristics are necessary in order to achieve 90 percent NOx reductions or greater across the proposed NTE control zone.

As discussed above, the use of advanced NOx adsorber based catalyst systems will present cold-start challenges for on-highway heavy-duty diesel engines, and for nonroad diesel engines, under our proposed Tier 4 program, similar to what light-duty gasoline manufacturers have faced in the past, due to the light-off characteristics of the NOx adsorber. We have previously discussed the tools available to engine manufacturers to overcome these challenges in order to achieve the NOx standard. The majority of engine operation which occurs within the proposed NTE control zone will occur at exhaust gas temperatures well above the light-off requirement of the NOx adsorbers. Figures 4.1-10 through 4.1-13 below show that all test modes which are within the proposed NTE control zone have exhaust gas temperatures greater than 300˚C which is well within the peak NOx reduction efficiency range of current generation NOx adsorbers. However, though the proposed NTE does not include engine start-up conditions, it is conceivable that a diesel which has not been warmed up could be started and very quickly be operated under conditions which are subject to the proposed NTE standard; for example, within a minute or less of vehicle operation after the vehicle has left an idle state. The proposed NTE regulations specify a minimum emissions sampling period of 30 seconds. Conceivably the vehicle emissions could be measured against the proposed NTE provisions during that first minute of operation, and in all likelihood it would not meet the proposed NTE NOx standard. Given that the NRTC standards will require control of cold-start emissions, manufacturers will be required to pay close attention to cold start to comply with the NRTC. As discussed above, operation with the proposed NTE will be at exhaust gas temperatures within the optimum NOx reduction operating window of the NOx adsorbers. In addition, the NOx adsorber is capable of adsorbing NOx at temperatures on the order of 100˚C. Figures 4.1-10 through 4.1-13 all show NOx emission reductions on the order of 70 - 80 percent are achieved at temperatures as low as 250˚C. Therefore, we have proposed to set a low temperature exhaust gas threshold of 250˚C, below which the specified NTE requirements do not apply, a provision we also adopted (for the same reason) for on-highway engines in our HD2007 program, and we are proposing a similar provision for Tier 4.

The proposed NTE requirements apply not only during laboratory conditions applicable to the transient test, but also under the wider range of ambient conditions for altitude, temperature and humidity specified in the regulations. These expanded conditions will have minimal impact on the emission control systems expected to be used to meet the proposed NTE NOx standard. In general, it can be said that the performance of the NOx adsorbers are only effected by the exhaust gas stream to which the adsorbers are exposed. Therefore, the impact of ambient humidity, temperature, and altitude will only effect the performance of the adsorber to the extent these ambient conditions change the exhaust gas conditions (i.e., exhaust gas temperature and gas constituents). The ambient humidity conditions subject to the proposed NTE requirement will have minimal, if any, impact on the performance of the NOx adsorbers. The exhaust gas itself, independent of the ambient humidity, contains a very high concentration of water vapor, and the impact of the ambient humidity on top of the products of dry air and fuel combustion are minimal. The effect of altitude on NOx adsorber performance should also be minimal, if any. The proposed NTE test procedure regulations specify an upper bound on NTE testing for altitude at 5,500 feet above sea-level. The decrease in atmospheric pressure at 5,500 feet should have minimal impact on the NOx adsorber performance. Increasing altitude can decrease the air-fuel ratio for diesel engines which can in turn increase exhaust gas temperatures; however, as discussed in the on-highway Phase1 (2004) final rule, Phase 1 technology HDDEs (and thus similar Tier 3 nonroad diesel engines) can be designed to target air-fuel ratios at altitude which will maintain appropriate exhaust gas temperatures, as well as maintain engine-out PM levels near the 0.1 g/bhp-hr level, within the ambient conditions specified by the on-highway NTE test procedure and thus the similar NTE procedure proposed today for Tier 4 nonroad engines. Finally, the proposed NTE regulations specify ambient temperatures which are broader than the NRTC temperature range of 68-86˚F. The proposed NTE test procedure specifies no lower ambient temperature bounds. However, as discussed above, we have proposed to limit NTE requirements on NOx (and NMHC) for engines equipped with NOx (and/or NMHC) catalysts to include only engine operation with exhaust gas temperatures greater than 250˚C. Therefore, low ambient temperatures will not present any difficulties for NTE NOx compliance. The proposed NTE also applies under ambient temperatures which are higher than the laboratory conditions. The proposed NTE applies up to a temperature of 100˚F at sea-level, and up to 86˚F at 5,500 feet above sea-level. At altitudes in between, the upper proposed NTE ambient temperature requirement is a linear fit between these two conditions. At 5,500 feet, the proposed NTE ambient temperature requirement is the same as the upper end of the FTP temperature range (86˚F), and therefore will have no impact on the performance of the NOx adsorbers, considering that majority of the test data described throughout this chapter was collected under laboratory conditions. The proposed NTE upper temperature limits at sea-level is 100˚F, which is 14˚F. (7.7˚C) greater than the NRTC range. This increase is relatively minor, and while it will increase the exhaust gas temperature, in practice the increase should be passed through the engine to the exhaust gas, and the exhaust gas would be on the order of 8˚C higher. Within the exhaust gas temperature range for a diesel engine during NTE operation, an 8˚C increase is very small. As discussed above, we expect manufacturer to choose an adsorber formulation which is matched to a particular engine design, and we would expect the small increase in exhaust gas temperature which can occur from the expanded ambient temperature requirements for the proposed NTE will be taken into account by the manufacturer when designing the complete emission control system.

To summarize, based on the information presented in this Chapter, and the analysis and discussion presented in this section, we conclude the proposed NTE NOx requirement (1.5 x NRTC/C1 standard) contained in this final rule will be feasible.

Further discussion of feasibility of the NOx requirement under transient testing conditions can be found in section 4.1.3 below (NRTC cycle) and in section 4.2 (CSVL cycle).

4.1.2.3.4 Are Diesel NOx Adsorbers Durable?

The considerable success in demonstrating NOx adsorbers makes us confident that the technology is capable of providing the level of conversion efficiency needed to meet the proposed NOx standard.

However, there are several engineering challenges that will need to be addressed in going from this level of demonstration to implementation of durable and effective emission control systems on nonroad equipment. In addition to the generic need to optimize engine operation to match the NOx adsorber performance, engine and catalyst manufacturers will further need to address issues of system and catalyst durability. The nature of these issues are understood well today. The hurdles that must be overcome have direct analogues in technology issues that have been addressed previously in automotive applications and are expected to be overcome with many of the same solutions. With the transfer of on-highway technologies to nonroad engines as anticipated in this rulemaking, all of the issues highlighted in this section while not addressed today, are expected to have already been addressed for on-highway engines well before the start of this nonroad program.

In this section we will describe the major technical hurdles to address in order to ensure that the significant emission reductions enabled through the application of NOx adsorbers is realized throughout the life of nonroad diesel engines. The section is organized into separate durability discussions for the system components (hardware) and various near and long term durability issues for the NOx adsorber catalyst itself.

4.1.2.3.4.1 NOx Adsorber Regeneration Hardware Durability

The system we have described in Figure 4.1-1 represents but one possible approach for generating the necessary exhaust conditions to allow for NOx adsorber regeneration and desulfation. The system consists of three catalyst substrates (for a CDPF/Low Temperature NOx Adsorber, a High Temperature NOx Adsorber and an Oxidation Catalyst), a support can that partitions the exhaust flow through the first two catalyst elements, three fuel injectors, and a means to divert exhaust flow through one or more of the catalyst partitions. Although not shown in the figure, a NOx /O_2 sensor is also likely to be needed for control feedback and on-board diagnostics(OBD). All of these elements have already been applied in one form or another to either diesel or gasoline engines in high volume long life applications.

The NOx adsorber system we described earlier borrows several components from the gasoline three-way catalyst systems and benefits from the years of development on three way catalysts. The catalyst substrates (the ceramic support elements on which a catalyst coating is applied) have developed through the years to address concerns with cracking due to thermal cycling and abrasive damage from vehicle vibration. The substrates applied for diesel NOx adsorbers will be virtually identical to the ones used for today’s passenger cars in every way but size. They are expected to be equally durable when applied to diesel applications as has already been shown in the successful application of diesel oxidation catalysts (DOCs) on some diesel engines over the last 15 years. Retrofit catalyst based systems have similarly been applied to nonroad diesel engines with good durability as described in 4.1.3.2 below.

The NOx/O_2 sensor needed for regeneration control and OBD is another component originally designed and developed for gasoline powered vehicles (in this case lean-burn gasoline vehicles) that are already well developed and can be applied with confidence in long life for NOx adsorber based diesel emission control. The NOx/O_2 sensor is an evolutionary technology based largely on the current Oxygen (O_2) sensor technology developed for gasoline three-way catalyst based systems. Oxygen sensors have proven to be extremely reliable and long lived in passenger car applications, which see significantly higher temperatures than would normally be encountered on a diesel engine.[52,53] Diesel engines do have one characteristic that makes the application of NOx/O_2 sensors more difficult. Soot in diesel exhaust can cause fouling of the NOx/O_2 sensor damaging its performance. However this issue can be addressed through the application of a catalyzed diesel particulate filter (CDPF) in front of the sensor. (See section 4.1.2.3.2 above, noting synergies that can result from use in tandem of NOx adsorbers and CDPFs.) The CDPF then provides a protection for the sensor from PM while not hindering its operation. Since the NOx adsorber is expected to be located downstream of a CDPF in each of the potential technology scenarios we have considered this solution to the issue of PM sooting is readily addressed.

Fuel is metered into a modern gasoline engine with relatively low pressure pulse-width-modulated fuel injection valves. These valves are designed to cycle well over a million times over the life of a vehicle while continuing to accurately meter fuel. Applying this technology to provide diesel fuel as a reductant for a NOx adsorber system is a relatively straightforward extension of the technology. A NOx adsorber system would expect to cycle far fewer times over its life when compared to the current long life of gasoline injectors. However, these gasoline fuel injectors designed to meter fuel into the relatively cool intake of a car cannot be directly applied to the exhaust of a diesel engine. In the testing done at NVFEL, a similar valve design was used that had been modified in material properties to allow application in the exhaust of an engine. Thus, while benefitting from the extensive experience with gasoline-based injectors a designer can, in a relatively straightforward manner, improve the characteristics of the injector to allow application for exhaust reductant regeneration. Toyota has shown with its Avensis DPNR diesel passenger car how to use a gasoline direct injection (GDI) based fuel injector to inject diesel fuel in the exhaust manifold of a diesel engine in order to allow for NOx adsorber regeneration and desulfation.[54]

The NOx adsorber system we describe in Figure 4.1-1 requires a means to partition the exhaust during regeneration and to control the relative amounts of exhaust flow between two or more regions of the exhaust system. Modern diesel engines already employ a valve designed to carry out this very task. Most modern turbochargers employ a wastegate valve that allows some amount of the exhaust flow to bypass the exhaust turbine in order to control maximum engine boost and limit turbocharger speed. These valves can be designed to be proportional, bypassing a specific fraction of the exhaust flow in order to track a specified boost pressure for the system. Turbocharger wastegate valves applied to heavy-duty diesel engines typically last the life of the engine in spite of the extremely harsh environment within the turbocharger. This same valve approach could be applied in order to accomplish the flow diversion required for diesel NOx adsorber regeneration and desulfation. Since temperatures will be typically cooler at the NOx adsorber compared to the inlet to the exhaust turbine on a turbocharger, the control valve would be expected to be equally reliable when applied in this application.

4.1.2.3.4.2 NOx Adsorber Catalyst Durability

In many ways a NOx adsorber, like other engine catalysts, acts like a small chemical process plant. It has specific chemical processes that it promotes under specific conditions with different elements of the catalyst materials. There is often an important sequence to the needed reactions and a need to match process rates in order to keep this sequence of reactions going. Because of this need to promote specific reactions under the right conditions early catalysts were often easily damaged. This damage prevents or slows one or more the reactions causing a loss in emission control.

For example, contaminants from engine oil, like phosphorous or zinc, could attach to catalysts sites partially blocking the site from the exhaust constituents and slowing reactions. Similarly, lead added to gasoline in order to increase octane levels bonds to the catalyst sites causing poisoning as well. Likewise, sulfur which occurs naturally in petroleum products like gasoline and diesel fuel can poison many catalyst functions preventing or slowing the desired reactions. High exhaust temperatures experienced under some conditions can cause the catalyst materials to sinter (thermally degrade) decreasing the surface area available for reactions to decrease.

All of these problems have been addressed over time for the gasoline three-way catalysts, resulting in the high efficiency and long life durability now typical of modern vehicles. In order to accomplish this changes were made to fuels and oils used in vehicles (e.g., lead additives banned from gasoline, sulfur levels reduced in gasoline distillates, specific oil formulations for aftertreatment equipped cars), and advances in catalysts designs were needed to promote sintering resistant catalyst formulations with high precious metal dispersion.

The wealth of experience gained and technological advancements made over the last 30 years of gasoline catalyst development can now be applied to the development of the NOx adsorber catalyst. The NOx adsorber is itself an incremental advancement from current three-way catalyst technology. It adds one important additional component not currently used on three-way catalysts, NOx storage catalyst sites. The NOx storage sites (normally alkali or alkaline earth metals) allow the catalyst to store NOx emissions with extremely high efficiency under the lean burn conditions typical of the diesel exhaust. It also adds a new durability concern due to sulfur storage on the catalyst.

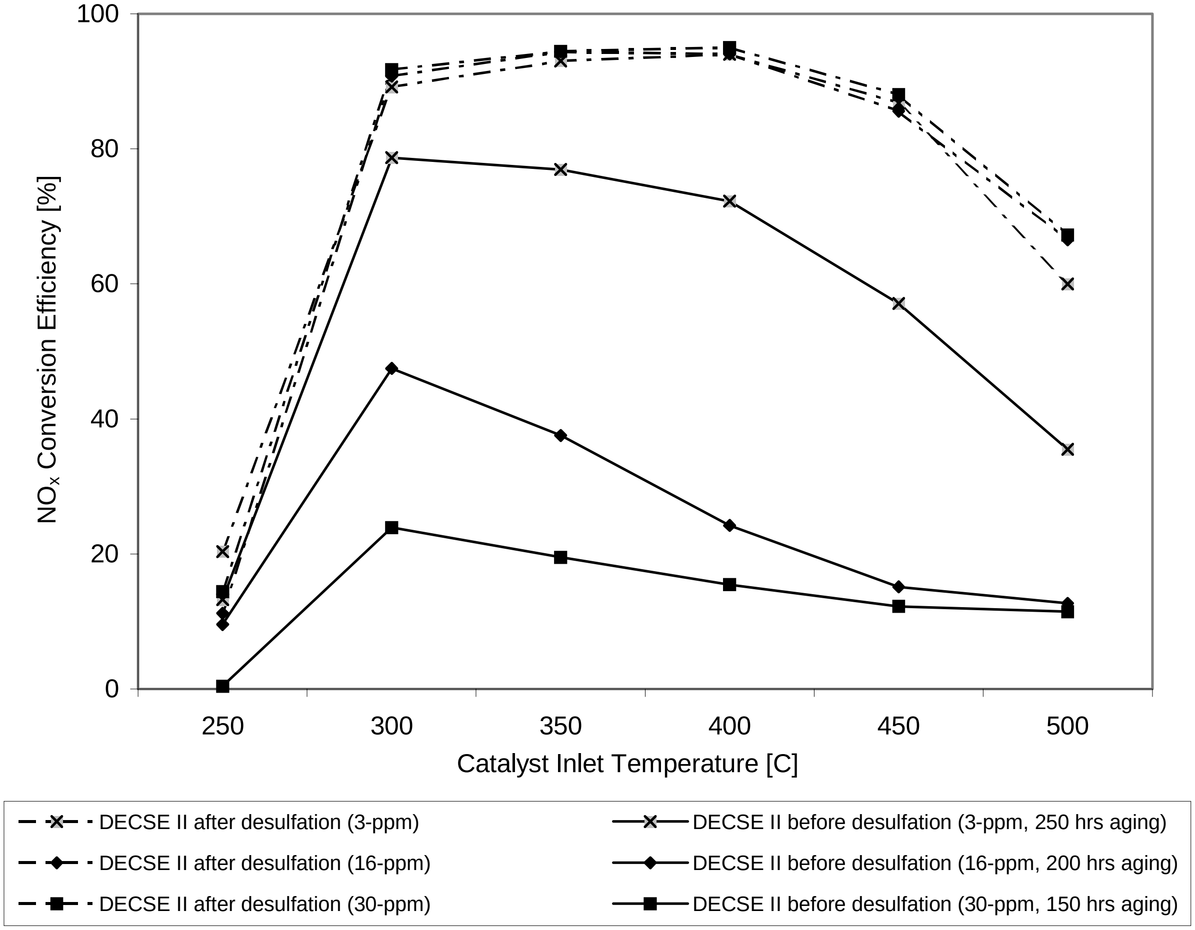
This section will explore the durability issues of the NOx adsorber catalyst applied to diesel engines. It describes the effect of sulfur in diesel fuel on catalyst performance, the methods to remove the sulfur from the catalyst through active control processes, and the implications for durability of these methods. It then discusses these durability issues relative to similar issues for existing gasoline three-way catalysts and the engineering paths to solve these issues. This discussion shows that the NOx adsorber is an incremental improvement upon the existing three-way catalyst, with many of the same solutions for the expected durability issues.

Sulfur Poisoning of the NOx Storage Sites

The NOx adsorber technology is extremely efficient at storing NOx as a nitrate on the surface of the catalyst, or adsorber (storage) bed, during lean operation. Because of the similarities in chemical properties of SOx and NOx, the SO_2 present in the exhaust is also stored on the catalyst surface as a sulfate. The sulfate compound that is formed is significantly more stable than the nitrate compound and is typically not released during the NOx release and reduction step (NOx regeneration step) (i.e. it is stored preferentially to NOx). Since the NOx adsorber is virtually 100 percent effective at capturing SO_2 in the adsorber bed, sulfate compounds quickly occupy the NOx storage sites on the catalyst thereby reducing and eventually rendering the catalyst ineffective for NOx reduction (poisoning the catalyst).

Figure 4.1-3 shows the effect of sulfur poisoning of a NOx adsorber catalyst as reported by the DOE DECSE program. The graph shows the NOx adsorber efficiency versus exhaust inlet temperature under steady-state conditions for a diesel engine based system. The three dashed lines that overlap each other show the NOx conversion efficiency of the catalyst when sulfur has been removed from the catalyst. The three solid lines show the effect of sulfur poisoning on the catalyst at three different fuel sulfur levels over different periods of extended aging (up to 250 hours). From the figure, it can be seen that even with three ppm sulfur fuel a significant loss in NOx efficiency can occur in as little as 250 hours. Further, it can be seen that quite severe sulfur poisoning can occur with elevated fuel sulfur levels. Catalyst performance was degraded by more than 70 percent over only 150 hours of operation when 30 ppm sulfur fuel was used.[55]

Figure 4.1-3
Comparison of NOx Conversion Efficiency before and after Desulfation



The DECSE researchers drew three important conclusions from Figure 4.1-3:

- Fuel sulfur, even at very low levels like three ppm, can limit the performance of the NOx adsorber catalyst significantly.

- Higher fuel sulfur levels, like 30 ppm, dramatically increase the poisoning rate, further limiting NOx adsorber performance.

- Most importantly though, the figure shows that if the sulfur can be removed from the catalyst through a desulfation (or desulfurization) event, the NOx adsorber can provide high NOx

> control even after exposure to sulfur in diesel fuel. This is evidenced by the sequence of the data presented in the figure. The three high conversion efficiency lines show the NOx conversion efficiencies after a desulfation event which was preceded by the sulfur poisoning and degradation shown in the solid lines.

The increase in sulfur poisoning rate is important to understand in order to look at the means to overcome the dramatic sulfur poisoning shown here. Sulfur accumulates in the NOx storage sites preventing their use for NOx storage. In other words, they decrease the storage volume of the catalyst. The rate at which sulfur fills NOx storage sites is expected to be directly proportional to the amount of sulfur that enters the catalyst. Therefore, for a doubling in fuel sulfur levels a corresponding doubling in the SOx poisoning rate would be predicted.

The design of a NOx adsorber will need to address accommodating an expected volume of sulfur before experiencing unacceptable penalties in either lost NOx control efficiency or increased fuel consumption due to more frequent NOx regenerations. The amount of operation allowed before that limit is realized for a specific adsorber design will be inversely proportional to fuel sulfur quantity. In the theoretical case of zero sulfur, the period of time before the sulfur poisoning degraded performance excessively would be infinite. For a more practical fuel sulfur level like the 10 ppm average expected with a 15 ppm fuel sulfur cap, the period of operation before unacceptable poisoning levels have been reached is expected to be less than 40 hours (with today's NOx adsorber formulations).[56]

Future improvements in the NOx adsorber technology are expected due to its relatively early state of development. Some of these improvements are likely to include improvements in the kinds of materials used in NOx adsorbers to increase the means and ease of removing stored sulfur from the catalyst bed. However, because the stored sulfate species are inherently more stable than the stored nitrate compounds (from stored NOx emissions), we expect that future NOx adsorbers will continue to be poisoned by sulfur in the exhaust. Therefore a separate sulfur release and reduction cycle (desulfation cycle) will always be needed in order to remove the stored sulfur.

NOx Adsorber Desulfation

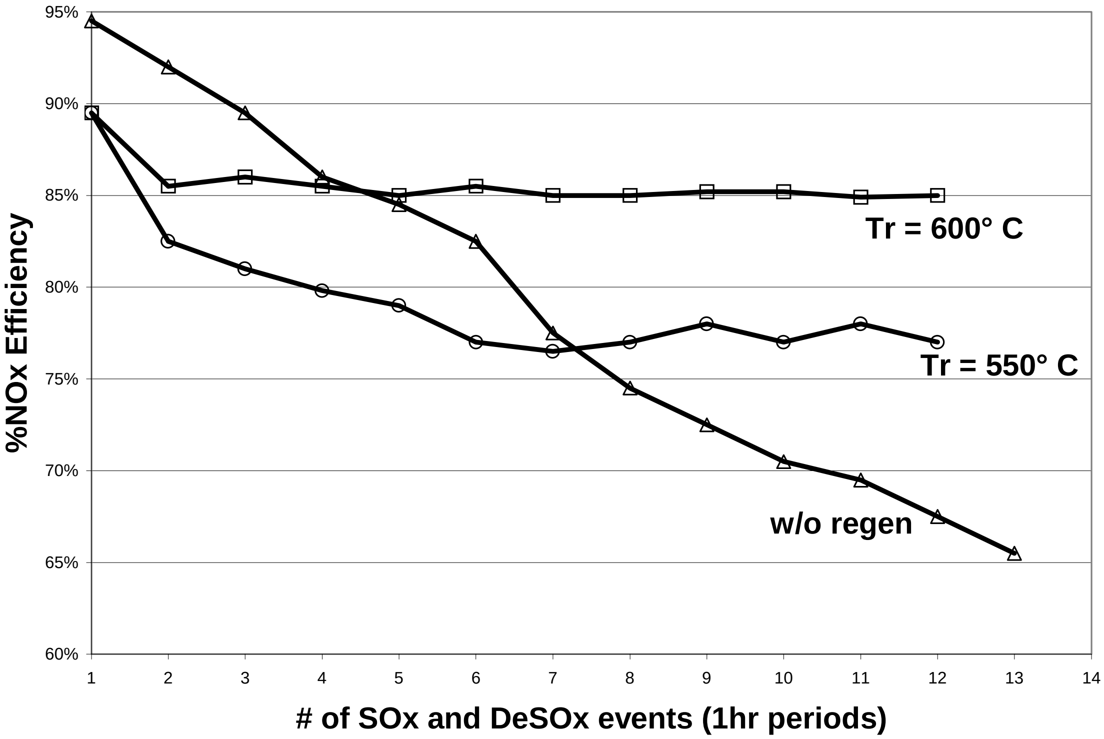
Numerous test programs have shown that sulfur can be removed from the catalyst surface through a sulfur regeneration step (desulfation step) not dissimilar from the NOx regeneration function.[57,58,59,60,61,62] The stored sulfur compounds are removed by exposing the catalyst to hot and rich (air-fuel ratio below the stoichiometric ratio of 14.5 to 1) conditions for a brief period. Under these conditions, the stored sulfate is released and reduced in the catalyst. This sulfur removal process, called desulfation or desulfurization in this document, can restore the performance of the NOx adsorber to near new operation.

Most of the information in the public domain on NOx adsorber desulfation is based upon research done either in controlled bench reactors using synthetic gas compositions or on advanced lean burn gasoline engine vehicles. As outlined above, these programs have shown that desulfation of NOx adsorber catalysts can be accomplished under certain conditions but the work does not directly answer whether NOx adsorber desulfation is practical for diesel engine exhaust conditions. The DECSE Phase II program answers that question.

Phase II of the DECSE program developed and demonstrated a desulfurization (desulfation) process to restore NOx conversion efficiency lost to sulfur contamination. The engine used in the testing was a high speed direct injection diesel selected to provide a representative source of diesel exhaust and various exhaust temperature profiles to challenge the emission control devices. The desulfation process developed in the DECSE Phase II program controlled the air to fuel ratio and catalyst inlet temperatures to achieve the high temperatures required to release the sulfur from the device. Air to fuel ratio control was accomplished in the program with exhaust gas recirculation (EGR) and a post injection of fuel to provide additional reductants. Using this approach the researchers showed that a desulfation procedure could be developed for a diesel engine with the potential to meet in-service engine operating conditions and acceptable levels of torque fluctuation. The NOx efficiency recovery accomplished in DECSE Phase II using this approach is shown in Figure 4.1-3, above.

The effectiveness of NOx adsorber desulfation appears to be closely related to the temperature of the exhaust gases during desulfation, the exhaust chemistry (relative air to fuel ratio), and to the NOx adsorber catalyst formulation.[63, 64] Lower air to fuel ratios (more available reductant) works to promote the release of sulfur from the surface, promoting faster and more effective desulfation. Figure 4.1-4 shows results from Ford testing on NOx adsorber conversion efficiency with periodic aging and desulfation events in a control flow reactor test.[65] The control flow reactor test uses controlled gas constituents that are meant to represent the potential exhaust gas constituents from a lean burn engine. The solid line with the open triangles labeled “w/o regen” shows the loss of NOx control over thirteen hours of testing without a desulfation event and with eight ppm sulfur in the test gas (this is roughly equivalent to 240 ppm fuel sulfur, assuming an air to fuel ratio for diesels of 30:1).[66] From the figure it can be seen that without a desulfation event, sulfur rapidly degrades the performance of the NOx adsorber catalyst. The remaining two lines show the NOx adsorber performance with periodic sulfur regeneration events timed at one hour intervals and lasting for 10 minutes (a one hour increment on 240 ppm fuel sulfur would be approximately equivalent to 34 hours of operation on seven ppm fuel). The desulfation events were identical to the NOx regeneration events, except that the desulfation events occurred at elevated temperatures. The base NOx regeneration temperature for the testing was 350˚C. The sulfur regeneration, or desulfation, event was conducted at two different gas temperatures of 550˚C and 600˚C to show the effect of exhaust gas temperature on desulfation effectiveness, and thus NOx adsorber efficiency. From Figure 4.1-4 it can be seen that, for this NOx adsorber formulation, the NOx recovery after desulfation is higher for the desulfation event at 600˚C than at 550˚C.

Figure 4.1-4
Flow Reactor Testing of a NOx Adsorber with Periodic Desulfations



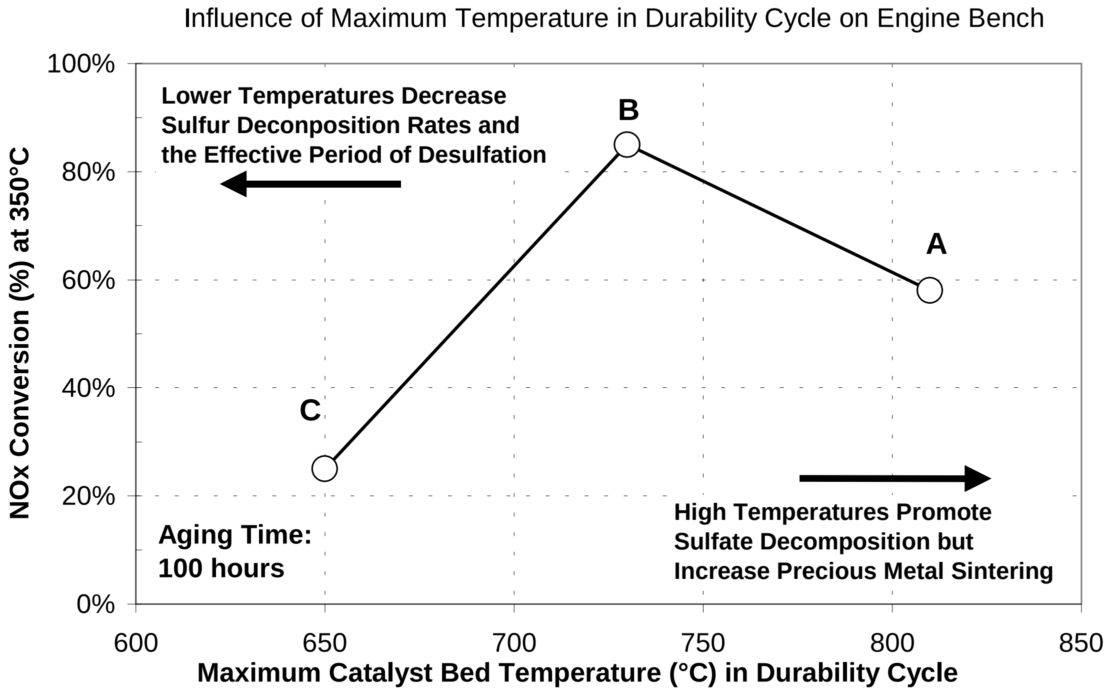
As suggested by Figure 4.1-4, it is well known that the rate of sulfur release (also called sulfur decomposition) in a NOx adsorber increases with temperature.[67,68] However, while elevated temperatures directionally promote more rapid sulfur release, they also can directionally promote sintering of the precious metals in the NOx adsorber washcoat. The loss of conversion efficiency due to exposure of the catalyst to elevated temperatures is referred to as thermal degradation in this document.

Thermal Degradation

The catalytic metals that make up most exhaust emission control technologies, including NOx adsorbers, are designed to be dispersed throughout the catalyst into as many small catalyst "sites" as possible. By spreading the catalytic metals into many small catalyst sites, rather than into a fewer number large sites, catalyst efficiency is improved. This is because smaller catalyst sites have more surface area per mass, or volume, of catalyst when compared to larger catalyst sites. Since most of the reactions being promoted by the catalyst occur on the surface, increasing surface area increases catalyst availability and thus conversion efficiency. While high dispersion (many small catalyst sites) is in general good for most catalysts, it is even more beneficial to the NOx adsorber catalyst because of the need for the catalytic metal sites to perform multiple tasks. NOx adsorber catalysts typically rely on platinum to oxidize NO to NO_2 prior to adsorption of the NO_2 on an adjacent NOx storage site. Under rich operating conditions, the NOx is released from the adsorption site, and the adjacent platinum (or platinum + rhodium) catalyst site can serve to reduce the NOx emissions into N_2 and O_2. High dispersion, combined with NO oxidation, NOx storage and NOx reduction catalyst sites being located in close proximity, provide the ideal catalyst design for a NOx adsorber catalyst. But high temperatures, especially under oxidizing conditions, can promote sintering of the platinum and other PGM catalyst sites, permanently decreasing NOx adsorber performance.

Catalyst sintering is a process by which adjacent catalyst sites can “melt” and regrow into a single larger catalyst site (crystal growth). The single larger catalyst site has less surface area available to promote catalytic activity than the original two or more catalyst sites that were sintered to form it. This loss in surface area decreases the efficiency of the catalyst.[69] High temperatures, promote sintering of platinum catalysts especially under oxidizing conditions.[70] Therefore, it is important to limit the exposure of platinum based catalysts to high exhaust temperatures especially during periods of lean operation. Consequently, the desire to promote rapid desulfation of the NOx adsorber catalyst technology by maximizing the desulfation temperature and the need to limit the exposure of the catalyst to the high temperatures that promote catalyst sintering must be carefully balanced. An example of this tradeoff can be seen in Figure 4.1-5 below, which shows the NOx conversion efficiency of three NOx adsorber catalysts evaluated after extended periods of sulfur poisoning followed by sulfur regeneration periods.[71] The three catalysts (labeled A, B, and C) are identical in formulation and size but were located at three different positions in the exhaust system of the gasoline direct injection engine used for this testing. Catalyst A was located 1.2 meters from the exhaust manifold, catalyst B 1.8 meters from the exhaust manifold and catalyst C was located 2.5 meters from the exhaust manifold. Locating the catalysts further from the engine lowered the maximum exhaust temperature and thus catalyst bed temperature experienced during the programmed sulfur regeneration cycle. Catalyst A experienced the highest catalyst bed temperature of 800˚C, while catalyst C experienced the lowest catalyst bed temperature of 650˚C. Catalyst B experienced a maximum catalyst bed temperature of 730˚C. Figure 4.1-5 shows that an optimum desulfation temperature exists which balances the tradeoffs between rapid sulfur regeneration and thermal degradation (thermal sintering) at high temperatures.

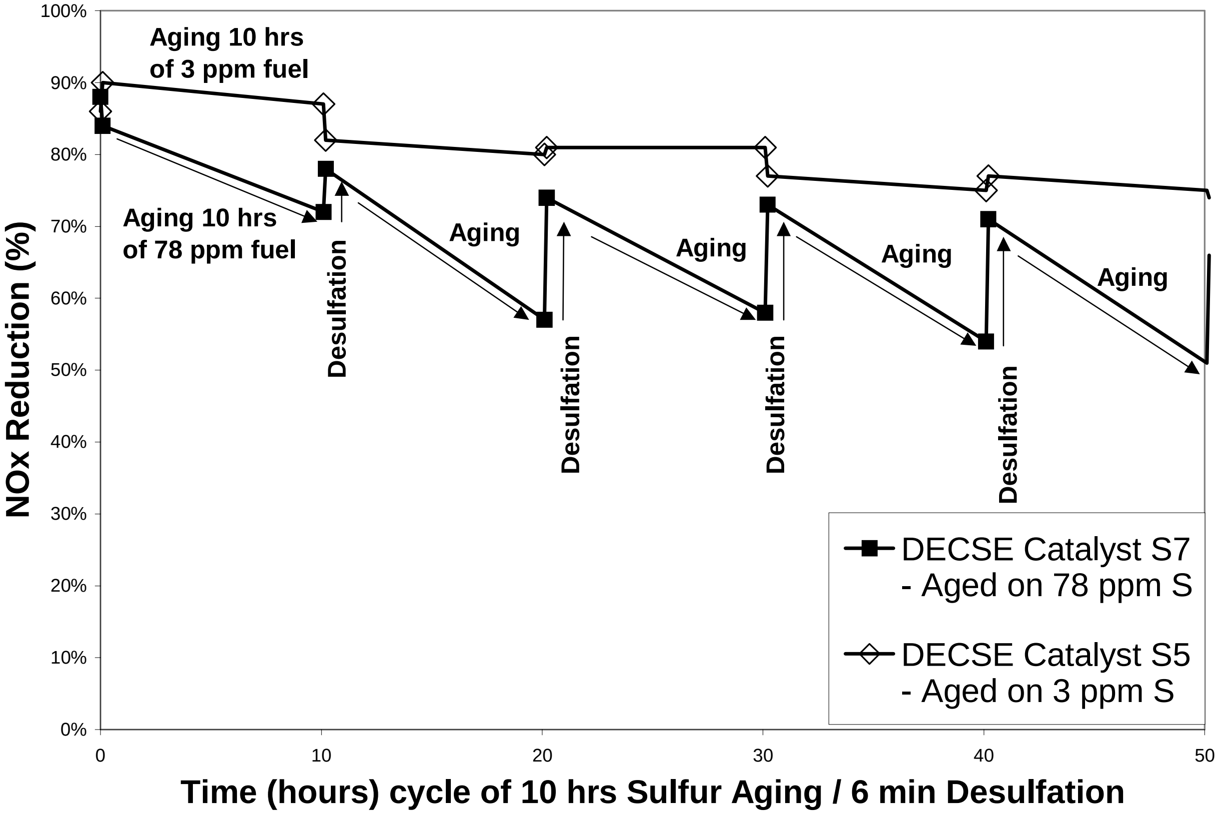
Figure 4.1-5
Influence of Maximum Catalyst Bed Temperature During Desulfation



From SAE 1999-01-3501 Figure 7

The DECSE Phase II program, in addition to investigating the ability of a diesel engine / NOx adsorber based emission control system to desulfate, provides a preliminary assessment of catalyst durability when exposed to repeated aging and desulfurization cycles. Two sets of tests were completed using two different fuel sulfur levels (three ppm and 78 ppm) to investigate these durability aspects. The first involved a series of aging, performance mapping, desulfurization and performance mapping cycles. An example of this testing is shown below in Figure 4.1-6. The graph shows a characteristic “sawtooth” pattern of gradual sulfur poisoning followed by an abrupt improvement in performance after desulfation. The results shown in Figure 4.1-6 are for two identical catalysts one operated on 3 ppm sulfur fuel (catalyst S5) and the other operated on 78 ppm sulfur fuel (catalyst S7). For the catalyst operated on 3 ppm sulfur fuel the loss in performance over the ten hours of poisoning is noted to be very gradual. There appears to be little need to desulfate that catalyst at the ten hour interval set in the experiment. In fact it can be seen that in several cases the performance after desulfation is worse than prior to desulfation. This would suggest as discussed above, that the desulfation cycle can itself be damaging to the catalyst. In actual use we would expect that an engine operating on 3 ppm sulfur fuel would not desulfate until well beyond a ten hour interval and would be engineered to better withstand the damage caused by desulfation, as discussed later in this section. For the catalyst operated on 78 ppm sulfur fuel the loss in performance over the ten hour poisoning period is dramatic. In order to ensure continued high performance when operating on 78 ppm sulfur fuel the catalyst would require frequent desulfations. From the figure it can be inferred that the desulfation events would need to be spaced at intervals as short as one to two hours in order to maintain acceptable performance.

Figure 4.1-6
Integrated NOx Conversion Efficiency following Aging and Desulfation



As a follow on to the work shown in Figure 4.1-6, the desulfation events were repeated an additional 60 times without sulfur aging between desulfation events. This was done to investigate the possibility of deleterious affects from the desulfation event itself even without additional sulfur poisoning. As can be seen in Figure 4.1-7, the investigation did reveal that repeated desulfation events even without additional sulfur aging can cause catalyst deterioration. As described previously, high temperatures can lead to a loss in catalyst efficiency due to thermal degradation (sintering of the catalytic metals). This appears to be the most likely explanation for the loss in catalyst efficiency shown here. For this testing, the catalyst inlet temperature was controlled to approximately 700˚C, however the catalyst bed temperatures could have been higher.[72]

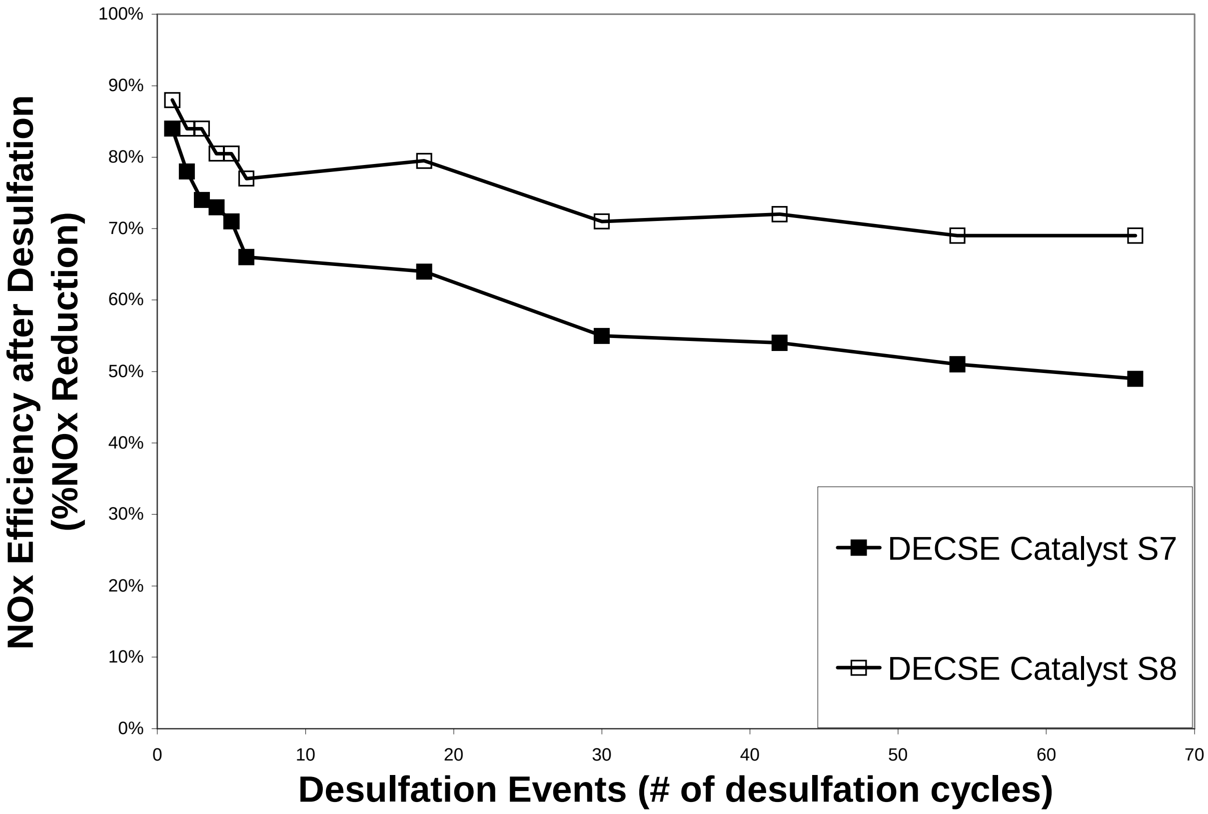
Based on the work in DECSE Phase II, the researchers concluded that:

- The desulfurization procedure developed has the potential to meet in-service engine operating conditions and to provide acceptable driveability conditions.

- Although aging with 78 ppm sulfur fuel reduced NOx conversion efficiency more than aging with three ppm sulfur fuel as a result of sulfur contamination, the desulfurization events restored the conversion efficiency to nearly the same level of performance. However, repeatedly exposing the catalyst to the desulfurization procedure developed in the program caused a continued decline in the catalyst's desulfated performance.

- The rate of sulfur contamination during aging with 78 ppm sulfur fuel increased with repeated aging / desulfurization cycles (from 10 percent per ten hours to 18 percent per ten hours). This was not observed with the three ppm sulfur fuel, where the rate of decline during aging was fairly constant at approximately two percent per ten hours.

Figure 4.1-7
Integrated NOx Conversion Efficiency after Repeated Desulfation



The data available today on current NOx adsorber formulations shows clearly that sulfur can be removed from the surface of the NOx adsorber catalyst. The initial high performance after a desulfation event is then degraded over time by the presence of sulfur until the next desulfation event. The resulting characteristic NOx adsorber performance level over time exhibits a saw-tooth pattern with declining performance followed by rapid recovery of performance following desulfation. The rate of this decline increases substantially with higher fuel sulfur levels. In order to ensure a gradual and controllable decline in performance fuel sulfur levels must be minimized. However, even given very low fuel sulfur levels, gradual decline in performance must be periodically overcome. The development experience so far shows that diesel engines can accomplish the required desulfation event. The circumstances that effectively promote rapid desulfation also promote thermal degradation. It will therefore be important to limit thermal degradation.

Limiting Thermal Degradation

The issue of thermal degradation of NOx adsorber catalyst components is similar to the thermal sintering issues faced by light-duty three-way catalysts for vehicles developed to meet current

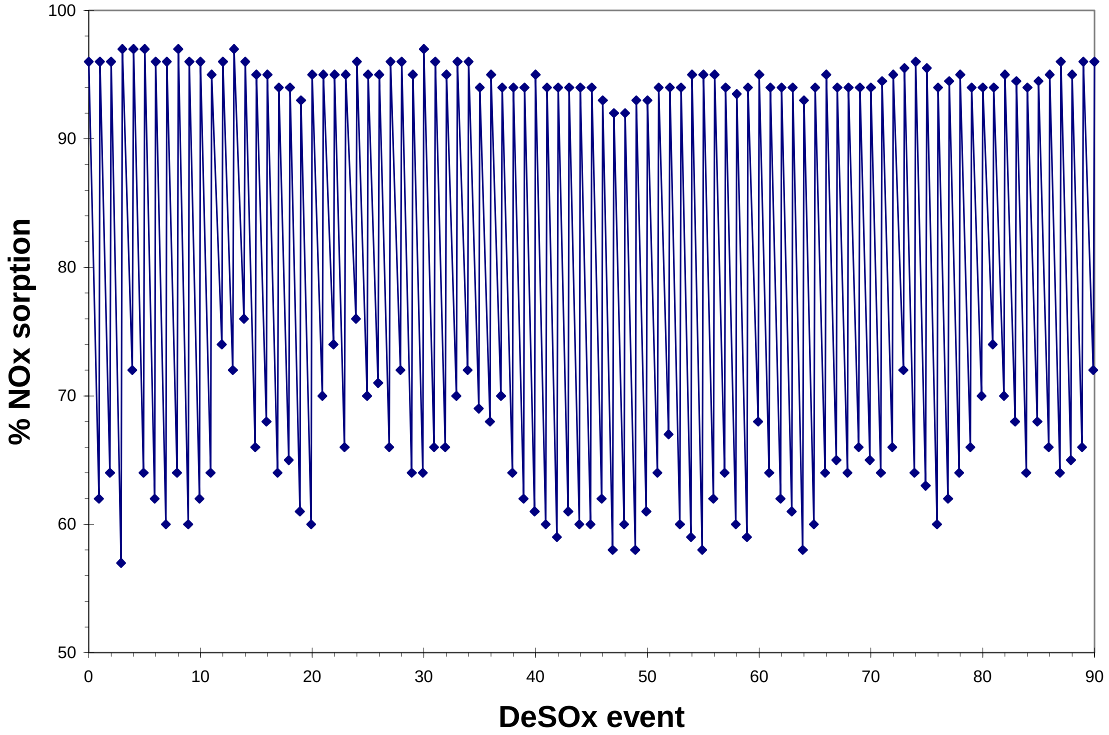
California LEV and future Federal Tier 2 standards using platinum+rhodium (Pt+Rh) catalysts. Initial designs were marked by unacceptable levels of platinum sintering which limited the effectiveness of Pt+Rh catalysts. This problem has been overcome through modifications to the catalyst supports and surface structures that stabilize the precious metals at high temperatures (>900 ˚C). Stabilization of ceria components using Zirconium (Zr) has pushed the upper temperature limits of ceria migration to well over 1000 ˚C.[73, 74] Stabilization components can function in a number of ways. Some are used to "fill" structural vacancies, for example "open" locations within a crystalline lattice, thus strengthening the lattice structure. Such strengthening of crystalline lattice structures is particularly important at high temperatures. Other types of stabilizing components can act as obstructions within a matrix to prevent migration of components, or can enhance the mobility of other molecules or atoms, such as oxygen. An approach to the stabilization of NOx adsorber catalyst components that is similar to the approaches taken with LEV three-way catalyst designs should help to minimize thermal sintering of components during desulfation.

In many ways, limiting the thermal degradation of the NOx adsorber catalyst should be easier than for the gasoline three-way catalyst. Typical exhaust gas temperatures for a heavy light-duty gasoline truck (e.g., a Ford Expedition) commonly range from 450˚C to more than 800˚C during normal operation.[75] A heavy-duty diesel engine in contrast rarely has exhaust gas temperatures in excess of 500˚C. Further, even during the desulfation event, exhaust temperatures are expected to be controlled below 700˚C. Therefore the NOx adsorber when applied to diesel engines is expected to see both lower average temperatures and lower peak temperatures when compared to an equivalent gasoline engine. Once thermal degradation improvements are made to NOx adsorber catalysts, thermal degradation will reasonably be expected to be less than the level predicted for future Tier 2 gasoline applications.

In addition to the means to improve the thermal stability of the NOx adsorber by applying many of the same techniques being perfected for the Tier 2 gasoline three-way catalyst applications, an additional possibility exists that the desulfation process itself can be improved to give both high sulfur removal and to limit thermal degradation. The means to do this might include careful control of the maximum temperature during desulfation in order to limit the exposure to high temperatures. Also, improvements in how the regeneration process occurs may provide avenues for improvement. Low air to fuel ratios (high levels of reductant) are known to improve the desulfation process. The high level of reductant may also help to suppress oxygen content in the exhaust to further limit thermal degradation.

Researchers at Ford Scientific Research Labs have investigated NOx adsorber catalyst desulfation (called DeSOx in their work) to answer the question: "if a regeneration process (sulfur regeneration) is required periodically, will the high temperatures required for the regeneration have deleterious, irreversible effects on NOx efficiency?" To explore the issue of NOx adsorber durability after repeated desulfation events, Ford conducted repeated sequential sulfur poisoning and desulfation cycles with a NOx adsorber catalyst. The results of their experiment are shown in Figure 4.1-8.[76] As shown in Figure 4.1-8, the NOx adsorber sample underwent more than 90 poisoning and desulfation cycles with 12 hours occurring between the end of one desulfation to the end of the next desulfation without a measurable loss in post-desulfation performance. This testing was done using a laboratory tool called a pulsator, used to study ceramic monolith catalyst samples. The ceramic test samples were heated to between 700˚C and 750˚C. These results indicate that for some combinations of temperatures and reductant chemistries the NOx adsorber can be repeatedly desulfated without a significant loss in NOx reduction efficiency. This work indicates that it is possible to optimize the desulfation process to allow for adequate sulfur removal without a significant decrease in NOx reduction efficiency.

Figure 4.1-8
Repeated Sulfur Poisoning and Desulfation on a Bench Pulsator



These results indicate that, with further improvements to the NOx adsorber catalyst design incorporating the experience gained on gasoline three-way catalysts and continuing improvements in the control of the desulfation, degradation of the NOx adsorber catalyst with each desulfation event can be limited. However, the expectation remains that there will be some level of deterioration with desulfation that must be managed to ensure long term high efficiency of the NOx adsorber. This means that the number and frequency of desulfation events must be kept to a minimum. The key to this is to limit the amount of sulfur to which the catalyst is exposed over its life. In this way, the deterioration in performance between desulfation events is controlled at a gradual rate and the period between desulfations can be maximized to limit thermal degradation.

Overall System Durability

NOx emission control with a NOx adsorber catalyst based systems is an extension of the very successful three-way catalyst technology. NOx adsorber technology is most accurately described as incremental and evolutionary with system components that are straightforward extensions of existing technologies. Therefore, the technology benefits substantially from the considerable experience gained over the past 30 years with the highly reliable and durable three-way catalyst systems of today.

The following observations can be made from the data provided in the preceding sections on NOx adsorber durability:

- NOx adsorber catalysts are poisoned by sulfur in diesel fuel, even at fuel sulfur levels as low as three ppm.
- A sulfur regeneration event (desulfation) can restore NOx adsorber performance.
- A diesel engine can produce exhaust conditions that are conducive to desulfation.
- Desulfation events which require high catalyst temperatures can cause sintering of the catalytic metals in the NOx adsorber thereby reducing NOx control efficiency.
- The means exist from the development of gasoline three-way catalysts to improve the NOx adsorber's thermal durability.
- In carefully controlled experiments, NOx adsorbers can be desulfated repeatedly without an unacceptable loss in performance.
- The number and frequency of desulfation events must be limited in order to ensure any gradual thermal degradation over time does not excessively deteriorate the catalyst.

Based on these observations, we are confident that NOx adsorber technology for MY2007 and later engines will be durable over the life of heavy-duty diesel vehicles, provided fuel with a 15 ppm sulfur cap is used and that the technology will prove to be similarly durable when applied some years later to nonroad diesel engines to comply with the proposed Tier 4 emission standards. Without the use of this low sulfur fuel, we can no longer be confident that the increased number of desulfation cycles that will be required to address the impact of sulfur on efficiency can be accomplished without unrecoverable thermal degradation and thus loss of NOx adsorber efficiency. Limiting the number and frequency of these deleterious desulfation events through the use of diesel fuel with sulfur content less than 15 ppm allows us to conclude with confidence that NOx adsorber catalysts will be developed that are durable throughout the life of a nonroad diesel engine.

4.1.2.3.5 Current Status of NOx Adsorber Development

NOx adsorber catalysts were first introduced in the power generation market less than five years ago. Since then, NOx adsorber systems in stationary source applications have enjoyed considerable success. In 1997, the South Coast Air Quality Management District of California determined that a NOx adsorber system provided the "Best Available Control Technology" NOx limit for gas turbine power systems.[77] Average NOx control for these power generation facilities is in excess of 92 percent.[78] A NOx adsorber catalyst applied to a natural gas fired powerplant has demonstrated better than 99 percent reliability for more than 21,000 hours of operation while controlling NOx by more than 90 percent.[79] The experience with NOx adsorbers in these stationary power applications shows that NOx adsorbers can be highly effective for controlling NOx emissions for extended periods of operation with high reliability.

4.1.2.3.5.1 Lean Burn Gasoline Engines

The NOx adsorber's ability to control NOx under oxygen rich (fuel lean) operating conditions has led industry to begin applying NOx adsorber technology to lean burn engines in mobile source applications. NOx adsorber catalysts have been developed and are now in production for lean burn gasoline vehicles in Japan, including several vehicle models sold by Toyota Motor Corporation.[H] The 2000 model year saw the first U.S. application of this technology with the introduction of the Honda Insight, certified to the California LEV-I ULEV category standard. Table 4.1-6 below lists some of the 2002 European lean-burn direct-injection gasoline vehicles which uses NOx adsorber catalyst technology.[80] These lean burn gasoline applications are of particular interest because they are similar to diesel vehicle applications in terms of lean NOx storage and the need for periodic NOx regeneration under transient driving conditions. The fact that they have been successfully applied to these mobile source applications shows clearly that NOx adsorbers can work under transient conditions provided that engineering solutions can be found to periodically cause normally lean-burn exhaust conditions to operate in a rich regeneration mode.

Table 4.1-6 2002 European Lean Burn Gasoline Direct-Injection Engines

Model	Displacement(liter)	Power(KW/PS)
Audi A2 FSI	1.6	81/110
Audi A4 FSI	2	110/150
BMW 760 iL	6	ca. 300/408
Citroen C5 HPI	2	103/140
Mercedes CLK 200 CGI	1.8	125/170
Mercedes C 200 CGI	1.8	125/170
Mitsubishi Carisma GDI	1.8	90/122
Mitsubishi Space Star GDI	1.8	90/122
Mitsubishi Space Wagon 2.4 GDI	2.4	108/147
Mitsubishi Space Runner 2.4 GDI	2.4	110/150
Mitsubishi Galant 2.4 GDI	2.4	106/144
Mitsubishi Pajero Pinin 2.0 GDI	2	90/122
Mitsubishi Pajero 3.2 V6 GDI	3.5	149/202
Peugeot 406 HPI	2	103/140
VW Lupo FSI	1.4	77/105
VW Polo FSI	1.4	63/85
VW Golf FSI	1.6	81/110
VW Bora FSI	1.6	81/110
Volvo S40 1.8	1.6	90/122

4.1.2.3.5.2 EPA National Vehicle and Fuel Emissions Laboratory (NVFEL)

As part of an ongoing effort to evaluate the rapidly developing state of this technology, the Manufacturers of Emission Control Association (MECA) have provided numerous NOx adsorber catalyst formulations to EPA for evaluation. Testing of some of these catalysts at the National Vehicle and Fuel Emission Laboratory (NVFEL) revealed that formulations were capable of reducing NOx emissions by more than 90 percent over the broad range of operation in the on-highway steady-

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[H] Toyota requires that their lean burn gasoline engines equipped with NOx adsorbers are fueled on premium gasoline in Japan, which has an average sulfur content of six ppm.

state SET procedure (sometimes called the EURO 4 test). At operating conditions representative of "road-load" operation for a heavy duty on-highway truck, the catalysts showed NOx reductions as high as 99 percent resulting in NOx emissions well below 0.1 g/bhp-hr from an engine out level of nearly 5 g/bhp-hr. Figure 4.1-9 shows an engine torque vs. speed map with the various steady-state test modes used in this testing as well as the 8 modes of the ISO-C1 cycle used for nonroad certification. Although not included in the test results shown in figures 4.1-10 through 4.1-12, the ISO-C1 modes are closely approximated by a number of other test modes as can be seen in figure 4.1-9. Therefore, we would expect similarly good performance on the ISO-C1 test modes. Testing on the on-highway transient test procedure has shown similarly good results, with hot start FTP NOx emissions reduced by more than 90 percent. These results demonstrate that significant NOx reductions are possible over a broad range of operating conditions with current NOx adsorber technology, as typified by the FTP and the SET procedure.

The test program at NVFEL can be divided into phases. The first phase began with an adsorber screening process using a single leg of the planned dual leg system. The goals of this screening process, a description of the test approach, and the results are described below. The next phase of the test program consisted of testing the dual leg system on a more advanced Tier 3 like diesel engine (i.e, with common rail fuel system and cooled EGR) using a NOx adsorber chosen during the first phase in each of two legs. The current ongoing phase is working on improved systems approaches including a demonstration of an improved package four "leg" system.

Testing Goals -- Single Leg NOx Adsorber System

The goal of the NOx adsorber screening process was to evaluate available NOx adsorber formulations from different manufacturers with the objective of choosing an adsorber with 90 percent or better NOx reduction for continued evaluation. To this end, four different adsorber formulations were provided from three different suppliers. Since this was a screening process and since a large number of each adsorber formulation would be required for a full dual leg system, it was decided to run half of a dual leg system (a single leg system) and mathematically correct the emissions and fuel economy impact to reflect a full dual leg system. The trade-off was that the single leg system would only be able to run steady state modes, as the emissions could not be corrected over a transient cycle. The configuration used for this test was similar to that shown in Figure 4.1-1, but with a catalyst installed on only one side of the system.

Test Approach -- Single Leg NOx Adsorber System

The single leg system consisted of an exhaust brake, a fuel injector, CDPF, and a NOx adsorber in one test leg. The other leg, the "bypass leg," consisted of an exhaust brake that opened when the test leg brake was closed; this vented the remainder of the exhaust out of the test cell. Under this set up, the test leg, i.e., the leg with the adsorber, was directed into the dilution tunnel where the emissions were measured and then compensated to account for emissions from the bypass leg. The restriction in the bypass leg was set to duplicate the backpressure of the test leg so that, while bypassing the test leg to conduct a NOx regeneration, the backpressure of the bypass leg simulated the presence of a NOx adsorber system. A clean-up diesel oxidation catalyst (DOC) downstream of the NOx adsorber was not used for this testing.

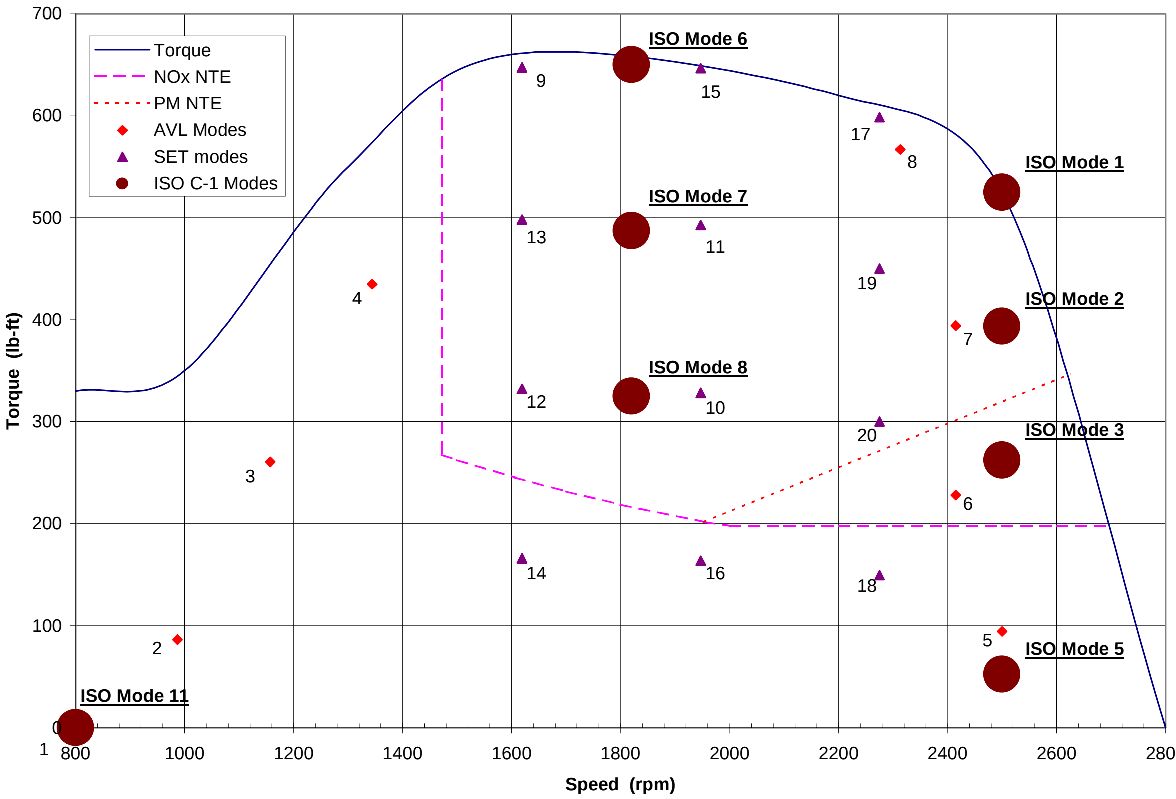
The measured emissions had to be adjusted to account for the lack of any NOx adsorber in the bypass leg. For this correction, it was assumed that the bypass leg's missing (virtual) adsorber would adsorb only while the actual leg was regenerating. It was also assumed the virtual adsorber would have regeneration fuel requirements in proportion to its adsorbing time. The emissions performance of the virtual adsorber was assumed to be the same as the performance of the actual adsorber. With these assumptions, the gaseous emissions could be adjusted.[81]

Test Results -- Single Leg NOx Adsorber System

Two sets of steady-state modes were run with each adsorber formulation. These modes consisted of the SET modes and the AVL 8 mode composite FTP prediction.[I] The modes are illustrated in Figure 4.1-9 and are numbered sequentially one through 20 to include both the eight AVL modes and the 13 SET modes (the idle mode is repeated in both tests). The mode numbers shown in the figure are denoted as "EPA" modes in the subsequent tables to differentiate between the AVL and SET modes which have duplicate mode numbers. The on-highway NTE (which, of course, is the same as the proposed nonroad NTE) zone is also shown in Figure 4.1-9 to show that these two sets of modes give comprehensive coverage of the proposed NTE zone. The ISO C1 steady-state modes used for nonroad engines are closely represented by the test modes shown here. The only C1 mode not well represented is the 10 percent load point (ISO Mode 5), which is outside of the proposed nonroad NTE zone. The modes were run with varying levels of automation, with the general strategy being to inject sufficient fuel during regeneration to obtain a lambda at or slightly fuel rich of stoichiometric ($\lambda \leq 1$). The NOx regenerations were then timed to achieve the desired NOx reduction performance. The adsorber formulations were identified as A, B, D, and E. Prior to testing, each set of adsorbers were aged at 2500 rpm, 150 lb-ft for 40 minutes, then 2500 rpm full load for 20 minutes, repeated for a total of 10 hours.

[I] The AVL 8 mode test procedure is a steady-state test procedure developed by Anstalt für Verbrennungskraftmaschinen, Prof. Dr. Hans List (or Institute for Internal Combustion Engines) to approximate the transient FTP.

Figure 4.1-9 Steady-State Test Modes from NVFEL Testing and ISO C-1 Modes



The SET and AVL Composite emission results, along with the NOx reduction performance vs. adsorber inlet temperature, are shown in Figures 4.1-10 through 4.1-13 for each of the tested NOx adsorber formulations. The SET composites for all four adsorber formulations had NOx reductions in excess of 90 percent with under a three percent FE impact. The HC emissions varied most widely, most likely due to differences in regeneration strategies, and to some extent, adsorber formulation. The HC emissions with the exception of adsorber “A” were very good, less than 0.1 g/hp-hr over the SET and less than 0.2 g/hp-hr over the AVL composite. It should be noted that no DOC was used to clean up the HC emissions.

Another point to note is that the EPA mode 1 (ISO-C1 Mode 11) data for each composite is the same. This is because EPA mode 1, low idle, is too cold for effective steady-state regeneration, but efficient NOx adsorption can occur for extended periods of time. (Note that the exhaust temperature at idle is well below the proposed NTE threshold of 250°C discussed earlier.) For either of these composite tests, a regeneration would not be needed under such conditions. EPA mode 1 has very little impact on either composite in any case because of the low power and emission rate. EPA mode 2 also had very low steady-state temperatures, and the difficulty regenerating at this mode can be seen in the HC and FE impacts. But, like EPA mode 1, EPA mode 2 would adsorb for extended periods of time without need for regeneration. None of the ISO-C1 modes, other than the idle mode, are similar to EPA mode 2. Further, no attempt was made to apply new combustion approaches such as the Toyota low temperature combustion technology in order to raise exhaust temperatures at these operating modes.

The AVL composite showed greater differences between the adsorber formulations than the SET. Three of the adsorbers achieved greater than 90 percent NOx reduction over the AVL composites with the other adsorber at 84 percent NOx reduction. The greater spread in NOx reduction performance was, in part, due to this composite's emphasis on EPA mode 8, which was at the upper end of the NOx reduction efficiency temperature window. Adsorber E had an EPA mode 8 NOx reduction of 66 percent, and the NOx reduction efficiency vs. inlet temperature graph clearly shows that this formulation's performance falls off quickly above 450˚C. In contrast, the other formulations do not show such an early, steep loss in performance. The FE impacts vary more widely also, partly due to the test engineers' regeneration strategies, particularly with the low temperature modes, and to the general inability to regenerate at very low temperature modes at steady-state. It should be noted that none of the regeneration strategies here can be considered fully optimized, as they reflect the product of trial and error experimentation by the test engineers. With further testing and understanding of the technology a more systematic means for optimization should be possible. In spite of the trial and error approach the results shown here are quite promising.

The AVL composite was developed as a steady state engine-out emission prediction of the HDDE transient cycle. As discussed in 4.1.3.1.2 below, NOx adsorber control effectiveness is projected to be more effective over the NRTC than over the on-highway HDDE transient cycle. With exhaust emission control devices, it loses some of its accuracy because of the inability of the emission control devices to be regenerated at the low temperature modes (EPA modes 1, 2, 5). In real world conditions, the HDDE does not come to steady-state temperatures at any of these modes, and the adsorber temperatures will be higher at EPA modes 1, 2, and 5 than the stabilized steady-state values used for this modal testing. Consequently, the actual HDDE transient cycle performance is expected to be much better than the composites would suggest (See discussion of transient testing below).

Based on the composite data and the temperature performance charts, amongst other factors, adsorber formulation B was chosen for further dual leg performance work. Both composites for this formulation were well above 90 percent. The NOx vs. temperature graph, Figure 4.1-11, also shows that this formulation was a very good match for this engine.

					Base	Adsorber				
EPA Mode	SET Mode	SET Weighting	Speed (rpm)	Torque (lb-ft)	BSNOx (g/hp-hr)	Inlet T (C)	BSNOx (g/hp-hr)	NOx Red	HC * (g/hp-hr)	FE Impact *
1	1	15%	Idle	0	13.0	144	0.16	100%	0.00	0.0%
9	2	8%	1619	630	4.6	461	0.11	98%	0.92	2.4%
10	3	10%	1947	328	4.7	357	0.07	98%	1.02	2.0%
11	4	10%	1947	493	5.0	411	0.06	99%	1.35	2.6%
12	5	5%	1619	332	5.0	384	0.13	97%	0.11	1.3%
13	6	5%	1619	498	5.0	427	0.24	95%	0.81	1.6%
14	7	5%	1619	166	5.5	287	0.25	95%	1.39	3.3%
15	8	9%	1947	630	4.0	498	0.89	78%	0.36	1.9%
16	9	10%	1947	164	5.0	293	0.14	97%	1.88	4.1%
17	10	8%	2275	599	4.0	515	0.48	88%	1.12	3.8%
18	11	5%	2275	150	4.8	282	0.42	91%	0.68	3.5%
19	12	5%	2275	450	5.0	404	0.08	98%	0.62	3.0%
20	13	5%	2275	300	4.8	357	0.14	97%	0.70	2.8%
Composite Results					4.6		0.31	93%	0.91 *	2.6% *

					Base	Adsorber				
EPA Mode	AVL Mode	AVL Weighting	Speed (rpm)	Torque (lb-ft)	BSNOx (g/hp-hr)	Inlet T (C)	BSNOx (g/hp-hr)	NOx Red	HC * (g/hp-hr)	FE Impact *
1	1	42%	Idle	0	13.00	144	0.16	100%	0.00	0.0%
2	2	8%	987	86	8.80	172	0.83	91%	0.75	7.7%
3	3	3%	1157	261	8.40	346	0.36	96%	1.10	3.1%
4	4	4%	1344	435	5.90	430	0.20	97%	2.16	3.0%
5	5	10%	2500	94	5.50	286	0.37	93%	4.93	3.6%
6	6	12%	2415	228	4.60	325	0.08	98%	2.30	3.6%
7	7	12%	2415	394	4.90	386	0.10	98%	2.38	3.1%
8	8	9%	2313	567	4.10	505	1.06	74%	0.03	1.9%
Composite Results					4.9		0.44	91%	1.69 *	2.9% *

* HC results & FE Impacts do not reflect future potential as they are derived using a 5 g NOx engine which requires more frequent NOx regens than would result using a 2.5 g engine and the tested system was not a fully optimized engine & emission control system.

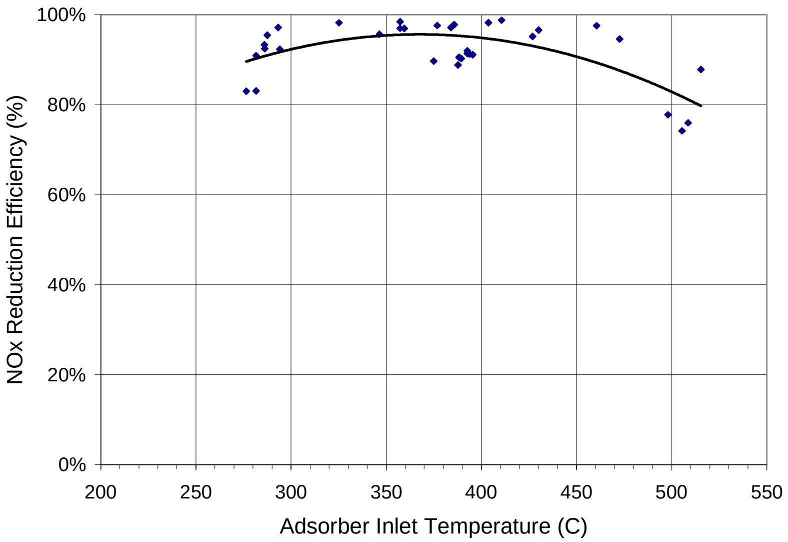


Figure 4.1-10. SET & AVL Composites, and Temperature vs. NOx Chart for Adsorber A

					Base	Adsorber				
EPA Mode	SET Mode	SET Weighting	Speed (rpm)	Torque (lb-ft)	BSNOx (g/hp-hr)	Inlet T (C)	BSNOx (g/hp-hr)	NOx Red	HC * (g/hp-hr)	FE Impact *
1	1	15%	Idle	0	13.0	144	0.16	100%	0.00	0.0%
9	2	8%	1619	630	4.6	498	0.18	96%	0.01	1.2%
10	3	10%	1947	328	4.7	366	0.07	98%	0.04	0.5%
11	4	10%	1947	493	5.0	446	0.14	97%	0.01	1.5%
12	5	5%	1619	332	5.0	375	0.06	99%	0.08	0.7%
13	6	5%	1619	498	5.0	420	0.07	98%	0.10	2.3%
14	7	5%	1619	166	5.5	296	0.18	97%	0.10	0.3%
15	8	9%	1947	630	4.0	524	0.46	89%	0.01	3.2%
16	9	10%	1947	164	5.0	293	0.36	93%	0.05	0.4%
17	10	8%	2275	599	4.0	537	0.56	86%	0.04	4.3%
18	11	5%	2275	150	4.8	280	0.29	94%	0.03	0.4%
19	12	5%	2275	450	5.0	426	0.24	95%	0.04	4.3%
20	13	5%	2275	300	4.8	357	0.11	98%	0.02	0.9%
Composite Results					4.6		0.27	94%	0.03 *	2.2% *

					Base	Adsorber				
EPA Mode	AVL Mode	AVL Weighting	Speed (rpm)	Torque (lb-ft)	BSNOx (g/hp-hr)	Inlet T (C)	BSNOx (g/hp-hr)	NOx Red	HC * (g/hp-hr)	FE Impact *
1	1	42%	Idle	0	13.00	144	0.16	100%	0.00	0.0%
2	2	8%	987	86	8.80	162	0.56	94%	2.11	1.8%
3	3	3%	1157	261	8.40	355	0.30	96%	0.16	0.3%
4	4	4%	1344	435	5.90	446	0.09	98%	0.23	0.9%
5	5	10%	2500	94	5.50	263	0.66	88%	0.25	1.6%
6	6	12%	2415	228	4.60	346	0.11	98%	0.03	0.4%
7	7	12%	2415	394	4.90	403	0.05	99%	0.02	1.4%
8	8	9%	2313	567	4.10	544	0.73	82%	0.35	4.0%
Composite Results					4.9		0.33	93%	0.19 *	2% *

* HC results & FE Impacts do not reflect future potential as they are derived using a 5 g NOx engine which requires more frequent NOx regens than would result using a 2.5 g engine and the tested system was not a fully optimized engine & emission control system.

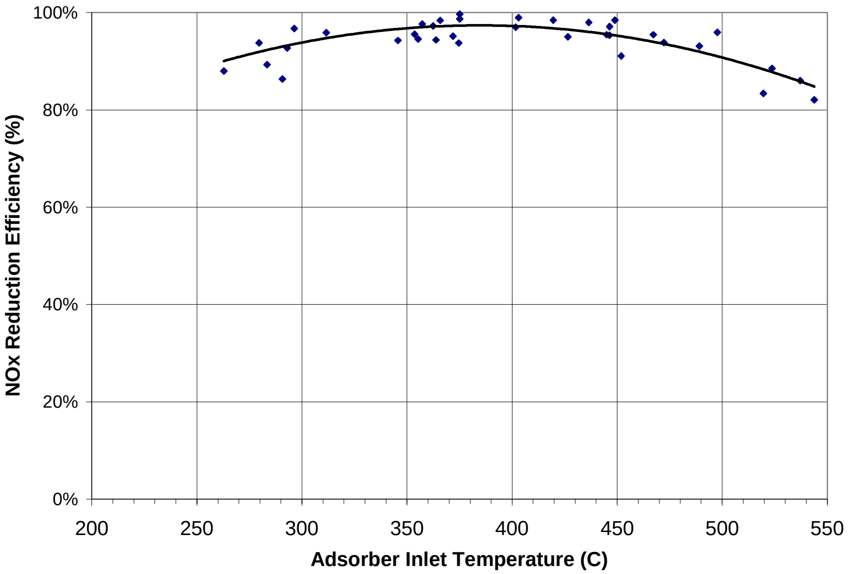


Figure 4.1-11. SET & AVL Composites, and Temperature vs. NOx Chart for Adsorber B

					Base	Adsorber				
EPA	SET	SET	Speed	Torque	BSNOx	Inlet T	BSNOx	NOx Red	HC *	FE Impact
Mode	Mode	Weighting	(rpm)	(lb-ft)	(g/hp-hr)	(C)	(g/hp-hr)		(g/hp-hr)	*
1	1	15%	Idle	0	13.00	144	0.16	100%	0.00	0.0%
9	2	8%	1619	630	4.60	451	0.18	96%	0.07	1.3%
10	3	10%	1947	328	4.70	356	0.14	97%	0.15	1.7%
11	4	10%	1947	493	5.00	400	0.09	98%	0.05	1.6%
12	5	5%	1619	332	5.00	377	0.07	99%	0.01	1.2%
13	6	5%	1619	498	5.00	431	0.11	98%	0.02	1.6%
14	7	5%	1619	166	5.50	305	0.23	96%	0.14	2.3%
15	8	9%	1947	630	4.00	501	0.16	96%	0.04	2.1%
16	9	10%	1947	164	5.00	303	0.15	97%	0.14	3.1%
17	10	8%	2275	599	4.00	489	0.93	93%	0.09	1.7%
18	11	5%	2275	150	4.80	278	0.57	88%	0.18	3.5%
19	12	5%	2275	450	5.00	391	0.12	98%	0.10	1.8%
20	13	5%	2275	300	4.80	330	0.21	96%	0.09	2.9%
Composite Results					4.6		0.28	94%	0.08 *	1.9% *

					Base	Adsorber				
EPA	AVL	AVL	Speed	Torque	BSNOx	Inlet T	BSNOx	NOx Red	HC *	FE Impact
Mode	Mode	Weighting	(rpm)	(lb-ft)	(g/hp-hr)	(C)	(g/hp-hr)		(g/hp-hr)	*
1	1	42%	Idle	0	13.00	144	0.16	100%	0.00	0.0%
2	2	8%	987	86	8.80	162	0.56	94%	2.11	1.8%
3	3	3%	1157	261	8.40	359	0.08	99%	0.30	3.1%
4	4	4%	1344	435	5.90	427	0.14	98%	0.19	1.7%
5	5	10%	2500	94	5.50	273	1.25	77%	0.26	6.4%
6	6	12%	2415	228	4.60	301	0.52	89%	0.13	1.9%
7	7	12%	2415	394	4.90	363	0.66	87%	0.04	1.4%
8	8	9%	2313	567	4.10	493	0.31	92%	0.08	1.6%
Composite Results					4.9		0.51	90%	0.14 *	1.9% *

* HC results & FE Impacts do not reflect future potential as they are derived using a 5 g NOx engine which requires more frequent NOx regens than would result using a 2.5 g engine and the tested system was not a fully optimized engine & emission control system.

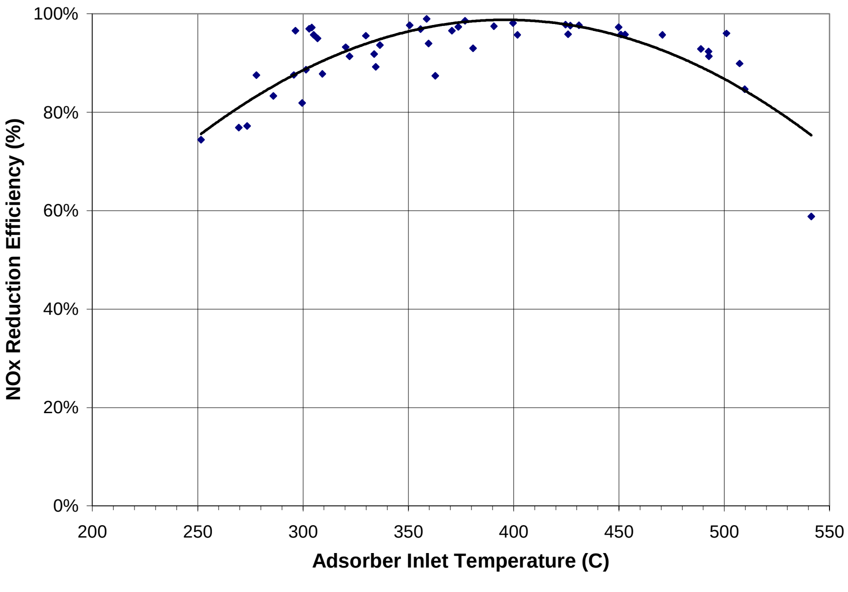


Figure 4.1-12. SET & AVL Composites, and Temperature vs. NOx Chart for Adsorber D

					Base	Adsorber				
EPA Mode	SET Mode	SET Weighting	Speed (rpm)	Torque (lb-ft)	BSNOx (g/hp-hr)	Inlet T (C)	BSNOx (g/hp-hr)	NOx Red	HC * (g/hp-hr)	FE Impact *
1	1	15%	Idle	0	13.00	144	0.16	100%	0.00	0.0%
9	2	8%	1619	630	4.60	455	0.47	89%	0.02	2.1%
10	3	10%	1947	328	4.70	343	0.07	98%	0.05	0.9%
11	4	10%	1947	493	5.00	442	0.36	93%	0.07	9.0%
12	5	5%	1619	332	5.00	377	0.08	98%	0.01	1.5%
13	6	5%	1619	498	5.00	419	0.29	94%	0.03	1.6%
14	7	5%	1619	166	5.50	412	0.14	98%	0.05	1.7%
15	8	9%	1947	630	4.00	392	0.05	99%	0.02	2.1%
16	9	10%	1947	164	5.00	294	0.09	98%	0.26	4.4%
17	10	8%	2275	599	4.00	492	0.95	76%	0.03	2.0%
18	11	5%	2275	150	4.80	388	0.11	98%	0.03	2.4%
19	12	5%	2275	450	5.00	391	0.12	98%	0.10	1.8%**
20	13	5%	2275	300	4.80	327	0.22	95%	0.02	1.4%
						** Md 19 data from Adsorber D				
		Composite Results			4.6		0.33	93%	0.05 *	2.9% *

					Base	Adsorber				
EPA Mode	AVL Mode	AVL Weighting	Speed (rpm)	Torque (lb-ft)	BSNOx (g/hp-hr)	Inlet T (C)	BSNOx (g/hp-hr)	NOx Red	HC * (g/hp-hr)	FE Impact *
1	1	42%	Idle	0	13.00	144	0.16	100%	0.00	0.0%
2	2	8%	987	86	8.80	166	7.39	16%	1.02	71.9%
3	3	3%	1157	261	8.40	339	0.09	99%	0.05	2.3%
4	4	4%	1344	435	5.90	449	0.65	89%	0.01	2.1%
5	5	10%	2500	94	5.50	256	1.36	75%	0.91	15.8%
6	6	12%	2415	228	4.60	313	0.35	92%	0.21	5.6%
7	7	12%	2415	394	4.90	372	0.12	97%	0.10	2.6%
8	8	9%	2313	567	4.10	508	1.39	66%	0.04	3.3%
		Composite Results			4.9		0.80	84%	0.16 *	5.4% *

* HC results & FE Impacts do not reflect future potential as they are derived using a 5 g NOx engine which requires more frequent NOx regens than would result using a 2.5 g engine and the tested system was not a fully optimized engine & emission control system.

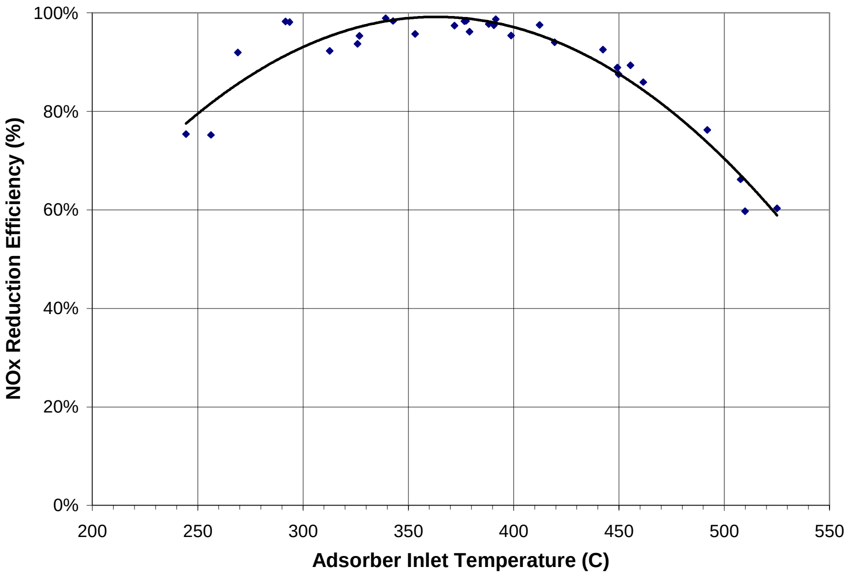


Figure 4.1-13. SET & AVL Composites, and Temperature vs. NOx Chart for Adsorber E

Testing Goals -- Dual Leg NOx Adsorber System

After completing the screening process and selecting NOx adsorber "B," the dual leg system was developed. The dual leg system was first tested on the same ISB engine as was used for the single leg testing. The results from that portion of the testing were similar to the single leg results (i.e., >90 percent NOx reductions for most test modes) and were reported in the HD2007 RIA.[82] Subsequent testing of the NOx adsorber system was made at NVFEL but with a new ISB engine that had been upgraded to include nonroad Tier 3 type technologies, such as common rail fuel injection and cooled EGR. The change in engine technology led to significantly lower engine out emissions (similar to the HD2004 levels and the expected Tier 3 levels) and to different exhaust gas temperature characteristics. As a result of the engine changes, the overall system performance was improved on both the steady-state test points and on the HD FTP transient test cycle.[83] As discussed further in 4.1.3.1.2 below, performance over the NRTC is projected to be better than for the on-highway HD FTP cycle. Also, as can be seen in figure 4.1-9 above, the SET steady-state test points are not significantly different from the ISO C1 test points (to which nonroad engines would be subject), therefore emissions reductions would be expected to be similar.

Testing Approach -- Dual Leg NOx Adsorber System

The steady state SET testing was conducted in a manner similar to that used in the screening process described above. The modes were run with varying levels of automation, with the general strategy being to inject sufficient fuel during regeneration to obtain a lambda at or slightly fuel rich of stoichiometric ($\lambda \leq 1$). The NOx regenerations were then timed to achieve the targeted 90 percent NOx reduction. The regeneration control and optimization strategies are described in more detail in an SAE paper included in the docket for this rule.[84]

The transient HDDE FTP regeneration control was accomplished using a time-based regeneration schedule. This control regenerated on a prescribed schedule of time and fuel quantities so that regenerations occurred at predetermined engine conditions during the transient cycle.

The transient HDDE FTP results presented here are for hot-start cycles only. The adsorber system was not optimized for cold start performance and would not provide a meaningful assessment of adsorber warmup performance. In order to better simulate the "cold-soak-hot" procedure called for in the HDDE FTP, a preconditioning mode was chosen to provide adsorber temperatures at the start of the "hot" cycle that would be similar to those found following the "cold-soak" portion of the test. The mode chosen was EPA mode 10 (1947 rpm, 328 lb-ft) which resulted in adsorber inlet temperatures (i.e., at the outlet of the CDPF) at the start of the hot cycle of about 280°C. Another purpose for the preconditioning was to ensure the adsorbers were in the same condition at the start of each test. Given that our regeneration control system did not automatically take into account the starting condition of the NOx adsorbers, this preconditioning was necessary to provide repeatable transient test results.

Test Results -- Dual Leg NOx Adsorber System

The on-highway SET is made up of the 13 Euro III modes. Several modes were run twice by different engineers, and the best calibration was chosen for the SET composite. Table 4.1-7 shows the SET composite test results. These data show that 90 percent NOx reductions were possible over the SET composite, with a modal NOx reduction range from 89 percent to nearly 100 percent. The adsorber NOx and HC reduction performance varied primarily as a function of exhaust temperature.

Figure Table 4.1-7 SET Results for Dual Leg System at NVFEL

Modal and composite SET NOx and HC emissions results for the Modified Cummins ISB engine.

Modified Cummins ISB (HPCR, cooled EGR)						**Modified Cummins ISB** (Baseline + CDPF and NOx adsorber catalysts)				
SET Mode	**SET Weighting**	**Speed (rpm)**	**Torque (lb-ft)**	**BSNOx (g/hp-hr)**	**BSHC (g/hp-hr)**	**Outlet T (°C)**	**BSNOx (g/hp-hr)**	**NOx (%-Reduction)**	**BSHC (g/hp-hr)**	**Reductant FE Impact (%)***
1	15%	Idle	0	6.95	6.77	144	0.16	100%	0.00	0.0%
2	8%	1649	633	3.10	0.08	529	0.33	89%	0.03	1.6%
3	10%	1951	324	1.79	0.21	403	0.06	96%	0.01	1.0%
4	10%	1953	490	1.98	0.12	486	0.07	96%	0.02	1.3%
5	5%	1631	328	1.90	0.22	403	0.10	95%	0.01	0.9%
6	5%	1626	496	2.35	0.09	504	0.07	97%	0.02	1.6%
7	5%	1623	161	2.05	0.56	313	0.02	99%	0.03	0.9%
8	9%	1979	609	2.09	0.08	524	0.19	91%	0.03	1.7%
9	10%	1951	159	1.68	0.49	323	0.01	100%	0.02	0.8%
10	8%	2348	560	1.95	0.11	524	0.10	95%	0.04	2.3%
11	5%	2279	145	1.66	0.57	306	0.01	99%	0.02	0.7%
12	5%	2275	447	1.84	0.14	465	0.10	95%	0.01	0.9%
13	5%	2274	296	1.76	0.25	400	0.03	98%	0.01	0.9%
SET Weighted Composite Results:				2.10	0.17		0.12	94%	0.03	1.4%**

Notes:
* Fuel economy impact of fuel-reductant addition for NOx adsorber regeneration.
** Increased exhaust restriction from the wall-flow and flow through monoliths results in a further FE impact of approximately 1-2% over the SET composite.

The FE impact was defined as the percent increase in fuel consumption caused by the adsorber regeneration fuel, or the mass of fuel used for regeneration, divided by the mass of fuel consumed by the engine during one regeneration and adsorption cycle. The FE impact varied from virtually 0 to 2.3 percent depending on the mode with a composite FE impact of 1.4 percent. We anticipate significant improvements in regeneration strategies are possible with different system configurations. Also, changes in engine operation designed to increase exhaust temperatures, not attempted in this work, can provide substantial improvements in catalyst performance and potentially a lower fuel economy impact.

HDDE Transient FTP Test Results

As with the steady-state test results, the hot-start FTP test results showed NOx and PM emissions in excess of 90 percent. The baseline (without the catalyst system) NOx emissions of 2.7 g/bhp-hr were reduced to 0.1 g/bhp-hr with the addition of the catalyst system, a better than 95 percent reduction in NOx emissions. Similarly, the PM emissions were reduced to below 0.003 g/bhp-hr from a baseline level of approximately 0.1 g/bhp-hr, a reduction of more than 95 percent. The fuel economy impact associated with regeneration of the NOx adsorber system was measured as 1.5 percent over the FTP cycle. The fuel economy impact associated with increased exhaust restriction from the CDPF was less than the measurement variability for the test cycle (i.e, less than 0.5 percent).[85]

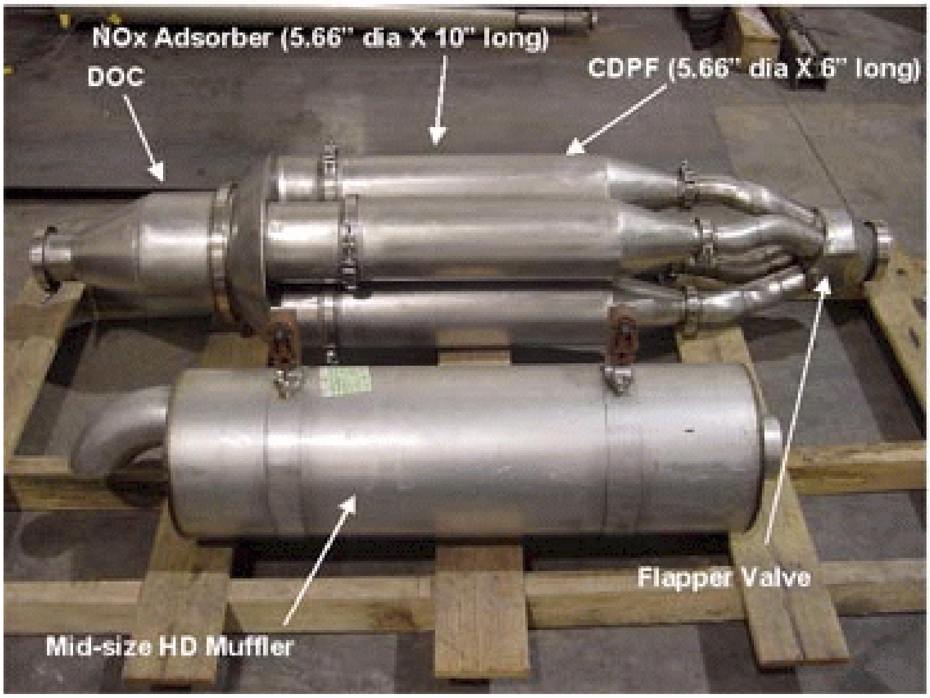
Durability Baseline NOx Adsorber Catalyst Testing

Additional testing was conducted at NVFEL to provide baseline performance data to gauge improvements in NOx adsorber durability performance in support of the 2007 Highway technology reviews. The data provides a look at the state of adsorber technology in 2001, with a glimpse of improvements that will be made in the future and is documented in a SAE paper.[86] It is clear from the analysis that there were vast differences in the durability performance of the formulations over these short tests. Adsorber suppliers were early on in their development and rapid improvements were being made. Two adsorbers representing one company's progress over 2 years showed significantly better aging performance (i.e., less degradation over time). This performance was evidenced by its NO_x adsorbing and regeneration performance after 100 hours.[87] In support of the U.S. EPA's continuing effort to monitor NO_x adsorber progress, new formulations are continuing to be evaluated.

Development of a Four "Leg" System Design

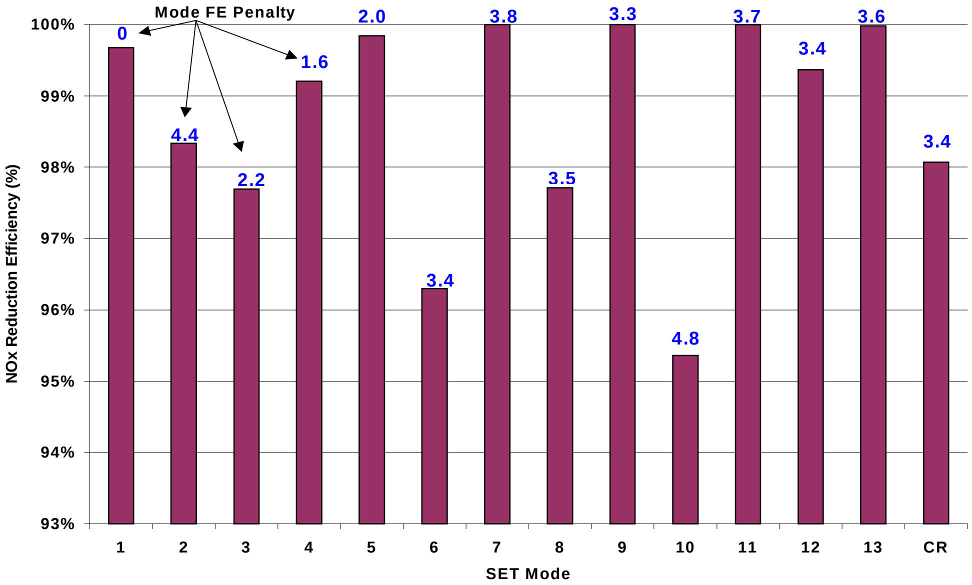
At NVFEL, developments have continued on methods and system designs for NOx adsorber catalyst technologies. A novel four leg NOx adsorber/PM trap system was developed as an evolution of the proof-of-concept two leg system that was used for previous testing at NVFEL (the system used in the test results reported here). The four leg system has a catalyst volume that is less than half of the volume of the two leg system. This allows the four leg system to be packaged in a volume not much larger than a muffler for a medium heavy duty truck application as can be seen in figure 4.1-14 below. Efforts have also been made to reduce the cost of the system by using simpler injectors and valve actuators.

Figure 4.1 -14 Prototype 4-leg System Compared to a Truck Muffler



Initial testing indicates that the four leg system at least matches the previous two leg systems NOx reduction efficiency with similar fuel consumption as can be seen in figure 4.1-15. Note that the results shown in the figure are based upon the NOx sensor data used in the control system. Work is underway to confirm these steady-state results and to demonstrate the performance over transient cycles.

Figure 4.1-15 Preliminary Results for Prototype 4 Leg System



4.1.2.3.5.3 Department of Energy (DOE) Test Programs

The U.S. Department of Energy (DOE) has funded several test programs at national laboratories and in partnership with industry to investigate the NOx adsorber technology. Most of these test programs are part of the Advanced Petroleum Based Fuel (APBF) program of DOE's Office of Transportation Technology (OTT). The initial phases of the programs are often referred to as the Diesel Emission Control Sulfur Effects (DECSE) program which is itself one of the APBF programs. Five reports documenting the DECSE program are available from the DOE OTT website (www.ott.doe.gov/decse) and were used extensively throughout our analysis.[88,89,90 91,92]

In the DECSE program, an advanced diesel engine equipped with common rail fuel injection and exhaust gas recirculation (EGR) was combined with a NOx adsorber catalyst to control NOx emissions. The system used an in-cylinder control approach. Rich regeneration conditions are created for the NOx adsorber catalyst regeneration through increased EGR rates and a secondary injection event designed to occur late enough in the engine cycle so as not to change engine torque output. Using this approach, the DECSE program has shown NOx conversion efficiencies exceeding 90 percent over a catalyst inlet operating temperature window of 300°C to 450°C. This performance level was achieved while staying within the four percent fuel economy penalty target defined for regeneration calibration.[93]

Subsequent work organized under the APBF program is commonly referred to as the APBF-Diesel Emission Control program, or APBF-DEC. The ongoing APBF-DEC work includes additional phases to develop prototype CDPF/NOx adsorber systems for a heavy-duty truck, a large sport utility vehicle and a passenger car. The program is looking at all important issues related to the technology including, packaging systems, effective regeneration, emissions performance and durability.[94]

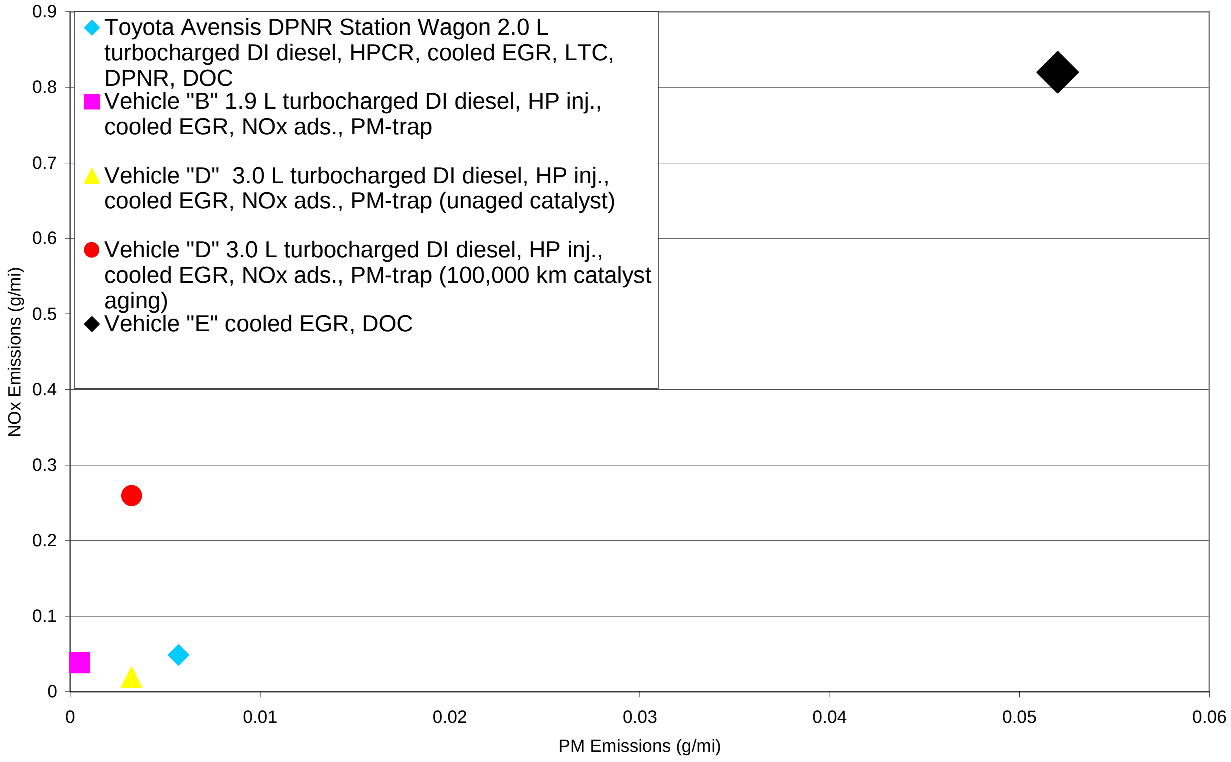
4.1.2.3.5.4 Heavy-Duty Engine Manufacturers

Heavy-duty diesel engine manufacturers (highway manufacturers) are currently developing systems to comply with the HD2007 emission standards including the NOx adsorber technology. As noted in the 2002 Highway Diesel Progress Review, which documents in more detail progress by the on-highway diesel engine industry to develop CDPF and NOx adsorber technology, the progress to develop these emission control systems is progressing rapidly. Although much of the work being done is protected as confidential business information, a recent public presentation by Daimler Chrysler Powersystems is illustrative some of the work that has been done prior to 2003.[95] The presentation reviews three possible system configurations for a combined CDPF / NOx adsorber system and compares the trade-offs among the approaches. Similar to the results shown in 4.1.2.3.5.3 by EPA, a dual leg system demonstrated 90 percent or higher NOx emissions control over a wide range of operation.

4.1.2.3.5.5 Light-Duty Diesel Vehicle Manufacturers

Diesel passenger car manufacturers are developing emission control systems using NOx adsorbers and PM filters in a combined control strategy to meet upcoming Euro IV emission standards for larger passenger cars and sedans in Europe and the light-duty Tier 2 emission standards in the United States. EPA has tested three prototype diesel passenger cars with these technologies over the last year. The results shown in figure 4.1-16 below demonstrate the potential for substantial reductions with NOx adsorber and PM filter technologies when tested with low sulfur diesel fuel. All three vehicles demonstrated substantial reductions in NOx and PM emissions when compared to a current day relatively clean (compared to only a few years ago) diesel passenger car as represented by the large black diamond on figure 4.1-16.

Figure 4.1-16 Tier 2 Passenger Car Prototypes Tested at NVFEL on the FTP75 Cycle



One vehicle in the test program, vehicle "D," was tested with both new catalyst hardware and aged catalyst hardware. The aged catalyst had experienced the equivalent of the 100,000 km of aging. The aged test results show that the aged catalyst system has lost some amount of NOx storage volume, causing the NOx emissions to breakthrough as the catalyst fills with NOx prior to the periodic NOx regenerations. In this testing, the NOx regeneration period was fixed for the new and aged catalyst at the same interval. It would appear from the data that the regeneration interval for the fresh catalyst was too infrequent for the aged catalyst which had a reduced NOx storage volume. At the very low NOx emissions levels shown in the figure, it only takes a very small breakthrough in NOx emissions to significantly increase the emissions over the lowest control levels. At the current time manufacturers are working to keep the number of regeneration episodes to the minimum number in order to minimize stress on catalyst materials (i.e., limit thermal degradation as discussed in section 4.2 above). We believe that manufacturers are continuing to develop more heat resistant materials that will reduce overall aging of the catalyst. If such materials had been available at this time, we believe that the NOx results for the aged vehicle would have been better. Note however, that the PM emissions show no deterioration for the aged system compared to the new system.

4.1.2.4 Selective Catalytic Reduction (SCR) Technology

Another NOx catalyst based emission control technology is selective catalytic reduction (SCR). SCR catalysts require a reductant, ammonia, to reduce NOx emissions. Because of the significant safety concerns with handling and storing ammonia, most SCR systems make ammonia within the catalyst system from urea. Such systems are commonly called urea SCR systems. Throughout this document the term SCR and urea SCR may be used interchangeably and should be considered as referring to the same urea based catalyst system. With the appropriate control system to meter urea in proportion to engine-out NOx emissions, urea SCR catalysts can reduce NOx emissions by over 90 percent for a significant fraction of the diesel engine operating range.[96] Although EPA has not done an extensive analysis to evaluate its effectiveness, we believe it may be possible to reduce NOx emissions with a urea SCR catalyst to levels consistent with compliance with today's proposed NOx standards.

We have significant concerns regarding a technology that requires extensive user intervention in order to function properly and the lack of the urea delivery infrastructure necessary to support this technology. Urea SCR systems consume urea in proportion to the engine-out NOx rate. The urea consumption rate can be on the order of five percent of the engine fuel consumption rate. Therefore, unless the urea tank is prohibitively large, the urea must be replenished frequently. Most urea systems are designed to be replenished every time fuel is added or at most every few times that fuel is added. Today, there is not a system in place to deliver or dispense automotive grade urea to diesel fueling stations. One study conducted for the National Renewable Energy Laboratory (NREL), estimated that if urea were to be distributed to every diesel fuel station in the United States, the cost would be more than $30 per gallon.[97]

We are not aware of a proven mechanism that ensures that the user will replenish the urea supply as necessary to maintain emissions performance. Further, we believe given the additional cost for urea, that there will be significant disincentives for the end-user to replenish the urea because the cost of urea could be avoided without equipment performance loss. See NRDC v. EPA, 655 F. 2d 318, 332 (D.C. Cir. 1981) (referring to "behavioral barriers to periodic restoration of a filter by a [vehicle] owner" as a valid basis for EPA considering a technology unavailable). Due to the lack of an infrastructure to deliver the needed urea, and the lack of a track record of successful ways to ensure urea use, we have concluded that the urea SCR technology is not likely to be available for general use in the time frame of the proposed standards. Therefore, we have not based the feasibility or cost analysis of this emission control program on the use or availability of the urea SCR technology. However, we would not preclude its use for compliance with the emission standards provided that a manufacturer could demonstrate satisfactorily to the Agency that urea would be used under all conditions. We believe that only a few unique applications will be able to be controlled in a manner such that urea use can be assured, and therefore believe it is inappropriate to base a national emission control program on a technology which can serve effectively only in a few niche applications.

This section has described a number of technologies that can reduce emissions from diesel engines. The following section describes the challenges to applying these diesel engine technologies to engines and equipment designed for nonroad applications.

4.1.3 Can These Technologies Be Applied to Nonroad Engines and Equipment?

The emission standards and the introduction dates for those standards, as described earlier in Section III of the preamble, are premised on the transfer of diesel engine technologies being, or already developed, to meet light-duty and heavy-duty vehicle standards that begin in 2007. The standards that we are proposing today for engines of 75 hp, or greater, will begin to go into effect four years later. This time lag between equivalent on-highway and nonroad diesel engine standards is necessary in order to allow time for engine and equipment manufacturers to further develop these on-highway technologies for nonroad engines and to align this program with nonroad Tier 3 emission standards that begin to go into effect in 2006.

The test procedures and regulations for the HD2007 on-highway engines include a transient test procedure, a broad steady-state procedure and NTE provisions that require compliant engines to emit at or below 1.5 times the regulated emission levels under virtually all conditions. An engine designed to comply with the 2007 highway emission standards would comply with the equivalent nonroad emission standards proposed today if it were to be tested over the transient and steady-state nonroad emission test procedures proposed today, which cover the same regions and types engine operation. Said in another way, an on-highway diesel engine produced in 2007 could be certified in compliance with the transient and steady-state standards proposed today for nonroad diesel engines several years in advance of the date when these standards would go into effect. However, that engine, while compliant with certain of the nonroad emission standards proposed today, would not necessarily be designed to address the various durability and performance requirements of many nonroad equipment manufacturers. We expect that the engine manufacturers will need additional time to further develop the necessary emission control systems to address some of the nonroad issues described below as well as to develop the appropriate calibrations for engine rated speed and torque characteristics required by the diverse range of nonroad equipment. Furthermore, not all nonroad engine manufacturers produce on-highway diesel engines or produce nonroad engines that are developed from on-highway products. Therefore, there is a need for lead time between the Tier 3 emission standards which go into effect in 2006-2008 and the Tier 4 emission standards. We believe the technologies developed to comply with the Tier 3 emission standards such as improved air handling systems and electronic fuel systems will form an essential technology baseline which manufacturers will need to initiate and control the various regeneration functions required of the catalyst based technologies for Tier 4. The Agency has given consideration to all of these issues in setting the emission standards and the timing of those standards as proposed today.

This section describes some of the challenges to applying advanced emission control technologies to nonroad engines and equipment, and why we believe that technologies developed for on-highway diesel engines can be further refined to address these issues in a timely manner for nonroad engines consistent with the emission standards proposed today.

4.1.3.1 Nonroad Operating Conditions and Exhaust Temperatures

Nonroad equipment is highly diverse in design, application, and typical operating conditions. This variety of operating conditions affects emission control systems through the resulting variation in the torque and speed demands (i.e. power demands). This wide range in what constitutes typical nonroad operation makes the design and implementation of advanced emission control technologies more difficult. The primary concern for catalyst based emission control technologies is exhaust temperature. In general, exhaust temperature increases with engine power and can vary dramatically as engine power demands vary.

For most catalytic emission control technologies there is a minimum temperature below which the chemical reactions necessary for emission control do not occur. The temperature above which substantial catalytic activities is realized is often called the light-off temperature. For gasoline engines, the light-off temperature is typically only important in determining cold start emissions. Once gasoline vehicle exhaust temperatures exceed the light-off temperature, the catalyst is “lit-off” and remains fully functional under all operating conditions. Diesel exhaust is significantly cooler than gasoline exhaust due to the diesel engine’s higher thermal efficiency and its operation under predominantly lean conditions. Absent control action taken by an electronic engine control system, diesel exhaust may fall below the light-off temperature of catalyst technology even when the engine is fully warmed up.

The relationship between the exhaust temperature of a nonroad diesel engine and light-off temperature is an important factor for both CDPF and NOx adsorber technologies. For the CDPF technology, exhaust temperature determines the rate of filter regeneration and if too low causes a need for supplemental means to ensure proper filter regeneration. In the case of the CDPF, it is the aggregate soot regeneration rate that is important, not the regeneration rate at any particular moment in time. A CDPF controls PM emissions under all conditions and can function properly (i.e., not plug) even when exhaust temperatures are low for an extended time and the regeneration rate is lower than the soot accumulation rate, provided that occasionally exhaust temperatures and thus the soot regeneration rate are increased enough to regenerate the CDPF. A CDPF can passively (without supplemental heat addition) regenerate if exhaust temperatures remain above 250˚C for more than 40 percent of engine operation.[98] Similarly (and as discussed in more detail earlier), there is a minimum temperature (e.g., 200˚C) for NOx adsorbers below which NOx regeneration is not readily possible and a maximum temperature (e.g., 500˚C) above which NOx adsorbers are unable to effectively store NOx. These minimum and maximum temperatures define a characteristic temperature window of the NOx adsorber catalyst. When the exhaust temperature is within the temperature window (above the minimum and below the maximum) the catalyst is highly effective. When exhaust temperatures fall outside this window of operation, NOx adsorber effectiveness is diminished. Therefore, there is a need to match diesel exhaust temperatures to conditions for effective catalyst operation under the various operating conditions of nonroad engines.

Although the range of products for on-highway vehicles is not as diverse as for nonroad equipment, the need to match exhaust temperatures to catalyst characteristics is still present. This is a significant concern for on-highway engine manufacturers and has been a focus of our ongoing diesel engine progress review. There we have learned that substantial progress is being made to broaden the operating temperature window of catalyst technologies, while at the same time, engine systems are being designed to better control exhaust temperatures. On-highway diesel engine manufacturers are working to address this need through modifications to engine design, modifications to engine control strategies and modifications to exhaust system designs. Engine design changes including the ability for multiple late fuel injections and the ability to control total air flow into the engine give controls engineers additional flexibility to change exhaust temperature characteristics. Modifications to the exhaust system, including the use of insulated exhaust manifolds and exhaust tubing, can help to preserve the temperature of the exhaust gases. New engine control strategies designed to take advantage of engine and exhaust system modifications can then be used to manage exhaust temperatures across a broad range of engine operation. The technology solutions being developed for on-highway engines to better manage exhaust temperature are built upon the same emission control technologies (i.e., advanced air handling systems and electronic fuel injection systems) that we expect nonroad engine manufacturers to use in order to comply with the Tier 3 emission standards.

4.1.3.1.1 CDPFS and Nonroad Operating Temperatures

EPA has conducted a screening analysis to better understand the effect of engine operating cycles and engine power density on exhaust temperatures, specifically to see if passive CDPF regeneration can be expected under all conditions for nonroad engine applications. Our approach for assessing the likelihood of passive regeneration by a CDPF is based on what we learned from the literature as well as information submitted by various catalyst manufacturers for product verification to our voluntary diesel retrofit program.

For this analysis three representative nonroad engines were tested. The engines are described in Table 4.1-8 below. In the case of the Cummins engine, the testing was done at three different engine ratings (250hp, 169hp, and 124hp) in order to evaluate the effect of engine power density on expected exhaust temperatures and therefore the likelihood of passive PM filter regeneration.

Table 4.1-8
Engines Tested to Evaluate PM Filter Regeneration

Engine Model	Model Year	Displacement (L)	Cylinder Number	Rated Power (hp)	Air Induction	Engine Type
Lombardini LDW1003-FOCS	2001	1.0	3	26	naturally aspirated	IDI
Kubota V2203-E	1999	2.2	4	50	naturally aspirated	IDI
Cummins ISB	2000	5.9	6	260	turbocharged intercooled	DI

As described earlier in this chapter, passive filter regeneration occurs when the exhaust temperatures are high enough that on aggregate the PM accumulation rate on the filter is less than the PM oxidation rate on the filter over an extended time period. During that time period there can be periods of low temperature operation where the PM accumulation rate is higher than the oxidation rates, provided that there are other periods of higher temperature operation where the PM oxidation rate is significantly higher than the accumulation rate. CDPF manufacturers provide guidelines for CDPF applications where passive regeneration is necessary (i.e., no provision for occasional active regeneration is provided). These guidelines are based on the cumulative amount of typical engine operation above and below a particular exhaust temperature. One CDPF manufacturer has stated that passive regeneration will occur if temperatures exceed 250°C for more than 30 percent of engine operation.[99] Another CDPF manufacturer has stated that catalyzed diesel particulate filters will work properly in the field if the engine exhaust temperature is at least 250-275°C for about 40-50 percent of the duty cycle.[100]

EPA used the more restrictive of these guidelines to evaluate the likelihood that passive regeneration would be realized on a number of typical nonroad operating cycles. To do this, the exhaust temperatures collected from testing each engine on various nonroad transient duty cycles were sorted in an ascending order. Upon sorting, we identified the 50th and 60th percentile mark of the temperature obtained for a transient cycle run, which lasted anywhere between 8 to 20 minutes for an entire cycle duration. The temperatures associated with the 50th and 60th percentile mark correspond to the minimum temperatures for 50 and 40 percent of the duty cycle, respectively. In addition, we also calculated the average temperature obtained throughout a given cycle.

Tables 4.1-9, 4.1-10, and 4.1-11 show the 50th and 60th percentile temperatures representing the minimum temperatures for 50% and 40% of the duty cycle, respectively. The tables show that the

60th percentile temperature exceeded 250ºC for most of the engine tests on all three engines. The runs which did not result in at least 250ºC for 40% of the duty cycle were from the on-highway FTP cycle for the two small engines, and from the backhoe cycle for the lowest power rating, i.e., 124 hp, on the Cummins ISB engine.

Table 4.1-9
Engine-out Exhaust gas temperature data - 124, 163, 260 hp Cummins ISB

Cycle		Average T (ºC)	50th %tile T (ºC)	60th %tile T (ºC)	Operation at T ≥ 275ºC
Agricultural Tractor	**260** hp (test #1454)	418	444	452	92%
	124 hp (test #1518)	319	336	339	89%
Wheel Loader	**260** hp (test #1449)	295	323	295	57%
	169 hp (test #1530)	264	277	311	50%
	124 hp (test #1526)	221	222	258	29%
Backhoe	**260** hp (test #1455)	261	280	303	52%
	169 hp (test #1528)	236	238	254	24%
	124 hp (test #1523)	185	194	201	0%
JRC Composite	**260** hp (test #1660)	311	323	337	75%
	260 hp (test #1661)	317	326	339	78%
	169 hp (test #1529)	289	290	304	61%
	124 hp (test #1525)	252	243	265	37%

Table 4.1-10
Engine-out exhaust gas temperature data - 50 hp Kubota V2203E

Cycle	Average T (ºC)	50th %tile T (ºC)	60th %tile T (ºC)	Operation at T ≥ 275ºC
Agricultural Tractor	518	544	561	96%
Nonroad Composite	289	286	310	56%
Skid Steer Loader	259	257	268	34%
Federal Test Procedure	232	210	238	30%

Table 4.1-11
Engine-out exhaust gas temperature data - 26 hp Lombardini LDW1003

Cycle	Average T (ºC)	50th %tile T (ºC)	60th %tile T (ºC)	Operation at T ≥ 275ºC
Arc Welder	262	257	263	26%
Nonroad Composite	274	271	290	48%
Skid Steer Loader	243	239	252	24%
Federal Test Procedure	177	148	175	15%
Agricultural Tractor**	516	548	554	97%

The results shown here lead us to conclude that, for a significant fraction of nonroad diesel engine operation, exhaust temperatures are likely to be high enough to ensure passive regeneration of CDPFs. However, the results also indicate that for some operating conditions it may be that passive filter regeneration is not realized. In the case of those operating conditions, we believe that active regeneration systems (systems designed to increase exhaust temperature periodically to initiate filter regeneration) can be used to ensure CDPF regeneration. Additional data regarding in-use temperature operation is contained in a recent report from the Engine Manufacturers Association (EMA) and the European Association of Internal Combustion Engine Manufacturers (Euromot).[101] This report contains data from a range of applications and power categories. The similar to the data presented above, the EMA/Euromot indicates that while a number of nonroad applications do generate temperatures high enough to passively regenerate a filter, there are also a number of applications which would require active regeneration.

We have assumed in our cost analysis that all nonroad engines complying with a PM standard of 0.02 g/bhp-hr or lower (those engines that we are projecting will use a CDPF) will have an active means to control temperature (i.e. we have costed a backup regeneration system, although some applications may not need one). We have made this assumption believing that manufacturers will not be able to predict, accurately, in-use conditions for every piece of equipment and will thus choose to provide the technologies on a back-up basis. As explained earlier, the technologies necessary to accomplish this temperature management are enhancements of the Tier 3 emission control technologies that will form the baseline for Tier 4 engines, and the control strategies being developed for on-highway diesel engines. We do not believe that there are any nonroad engine applications above 25 horsepower for which these highway engine approaches will not work. However, given the diversity in nonroad equipment design and application, we believe that additional time will be needed in order to match the engine performance characteristics to the full range of nonroad equipment.

We believe that given the timing of the emissions standards proposed today, and the availability and continuing development of technologies to address temperature management for on-highway engines which technologies are transferrable to all nonroad engines with greater than 25 hp power rating, that nonroad engines can be designed to meet the proposed standards in a timely manner.

Matching the operating temperature window of the broad range of nonroad equipment may be somewhat more challenging for nonroad engines than for many on-highway diesel engines simply because of the diversity in equipment design and equipment use. Nonetheless, the problem has been successfully solved in on-highway applications facing low temperature performance situations as difficult to address as any encountered faced by nonroad applications. The most challenging temperature regime for on-highway engines are encountered at very light-loads as typified by congested urban driving. Under congested urban driving conditions exhaust temperatures may be too low for effective NOx reduction with a NOx adsorber catalyst. Similarly, exhaust temperatures may be too low to ensure passive CDPF regeneration. To address these concerns, light-duty diesel engine manufacturers have developed active temperature management strategies that provide effective emissions control even under these difficult light-load conditions. Toyota has shown with their prototype DPNR vehicles that changes to EGR and fuel injection strategies can realize an increase in exhaust temperatures of more than 50°C under even very light-load conditions allowing the NOx adsorber catalyst to function under these normally cold exhaust conditions.[102] Similarly, PSA has demonstrated effective CDPF regeneration under demanding light-load taxi cab conditions with current production technologies.[103] Both of these are examples of technology paths available to nonroad engine manufacturers to increase temperatures under light-load conditions.

We are not aware of any nonroad equipment in-use operating cycles which would be considered to be more demanding of low temperature performance than on-highway urban driving. Both the Toyota and PSA systems are designed to function even with extended idle operation as would be typified by a taxi waiting to pick up a fare.[J] By actively managing exhaust temperatures engine manufacturers can ensure highly effective catalyst based emission control performance (i.e., compliance with the emission standards) and reliable filter regeneration (failsafe operation) across a wide range of engine operation as would be typified by the broad range of in-use nonroad duty cycles and the new nonroad transient test proposed today.

The systems described here from Toyota and PSA are examples of highly integrated engine and exhaust emission control systems based upon active engine management designed to facilitate catalyst function. Because these systems are based upon the same engine control technologies likely to be used to comply with the Tier 3 standards and because they allow great flexibility to trade-off engine control and catalyst control approaches depending on operating mode and need, we believe most nonroad engine manufacturers will use similar approaches to comply with the emission standards proposed today. However, there are other technologies available that are designed to be added to existing engines without the need for extensive integration and engine management strategies. One example of such a system is an active DPF system developed by Deutz for use on a wide range on nonroad equipment. The Deutz system has been sold as an OEM retrofit technology that does not require changes to the base engine technology. The system is electronically controlled and uses supplemental in-exhaust fuel injection to raise exhaust temperatures periodically to regenerate the DPF. Deutz has sold over 2,000 of these units and reports that the systems have been reliable and effective. Some manufacturers may choose to use this approach for compliance with the PM standard proposed today, especially in the case of engines which may be able to comply with the proposed NOx standards with engine-out emission control technologies (i.e., engines rated between 25 and 75 horsepower).

4.1.3.1.2 NOx Adsorbers and Nonroad Operating Temperatures

Section 4.1.2.3.3 above describes a method to directionally evaluate the match between the operating temperature characteristics of a diesel engine in typical use and the range of temperatures over which a NOx adsorber catalyst is highly effective, the operating window of the NOx adsorber catalyst technology. The analysis is not effective to accurately predict exact emission results as it

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[J] There is one important distinction between the current PSA system and the kind of system that we project industry will use to comply with the Tier 4 standards: the PSA system incorporates a cerium fuel additive to help promote soot oxidation. The additive serves a similar function to a catalyst to promote soot oxidation at lower temperatures. Even with the use of the fuel additive, passive regeneration is not realized on the PSA system and an active regeneration is conducted periodically involving late cycle fuel injection and oxidation of the fuel on an up-front diesel oxidation catalyst to raise exhaust temperatures. This form of supplemental heating to ensure infrequent but periodic PM filter regeneration has proven to be robust and reliable for more than 400,000 PSA vehicles. Our 2002 progress review found that other manufacturers will be introducing similar systems in the next few years without the use of a fuel additive. One vehicle manufacturer, Renault has recently announced that they will introduce this year a CDPF system on a diesel passenger car that does not rely on an additive to help ensure that regeneration occurs.

does not account for the thermal inertia of the catalyst technologies nor the ability of the NOx adsorber to store NOx at lower temperatures as discussed in more fully in Section 4.1.2.3.3. Nevertheless, this analysis approach can be used to compare predicted performance of an engine with a NOx adsorber catalyst on various test cycles and with various engine configurations.

In this case, we have used this analysis approach to better understand the characteristics of the NRTC and the C1 composite cycle relative to the on-highway FTP test cycle. We have extensive experience testing NOx adsorber catalyst systems on the on-highway FTP procedure (see discussion above in Section 4.2) showing that NOx reductions in excess of 90% can be expected. Here, we are trying to understand if the NOx performance on the NRTC and the C1 composite cycle should be expected to be better or worse than the on-highway FTP cycle. To accomplish that, we tested a Cummins ISB (see Table 4.1-8 above) engine at three different power ratings representative of the range of engine power density currently seen for nonroad diesel engines (250hp, 169hp, and 124hp). Following the technique described in Section 4.1.2.3.3, we estimated a notional NOx adsorber efficiency for the various test cycles and engine power ratings described here. Further, we performed this analysis for several different NOx adsorber mounting locations (i.e., we measured exhaust temperatures at several locations in the exhaust system, a catalyst is not actually installed for this testing). By measuring temperature at several locations, we could further understand the impact of heat loss in the exhaust system on NOx adsorber performance. The results of this testing and analysis are presented in tables 4.1-12, 4.1-13 and 4.1-14 below.

Table 4.1-12
Estimated NOx Adsorber Efficiency on Cummins ISB ISO-C1 Composite

Engine Power (hp)	6" from turbo outlet (%)	25" from turbo outlet (%)	4' from turbo outlet (%)	6' 7" from turbo outlet (%)
124	90.5	90.7	90.6	89.8
169	86.2	87.1	88.7	90.8
250	79.5	84.2	85.2	87.9

‡ The estimates are based on the absorber B curve shown in Figure 4.1-11.

Table 4.1-13
Estimated NOx Adsorber Efficiency on Cummins ISB - NRTC Cycle

Engine Power (hp)	6" from turbo outlet (%)	25" from turbo outlet (%)	4' from turbo outlet (%)	6' 7" from turbo outlet (%)
124	85.6	83.9	81.7	77.4
169	93.0	92.2	91.1	88.6
250	91.6	92.9	93.6	93.5

‡ The estimates are based on the absorber B curve shown in Figure 4.1-11.

Table 4.1-14
Estimated NOx Adsorber Efficiency on Cummins ISB - FTP Cycle

Engine Power (hp)	6" from turbo outlet (%)
124	60.3
169	72.4
250	83.0

A The estimates are based on the absorber B curve shown in Figure 4.1-11.

Results of the analysis show that for many nonroad engines, the expected exhaust temperatures are well matched for NOx adsorber control giving high NOx conversion efficiencies with today's NOx adsorber technology. The NOx reduction potential by these devices was higher over nonroad cycles when compared to that achieved from the on-highway FTP cycle. This higher efficiency obtained from the engine testing results was due to comparatively higher engine-out exhaust temperatures obtained from running on various nonroad transient cycles compared to the on-highway FTP cycle, thus indicating that the transfer of on-highway technologies developed for the HD2007 emission standards will be able to provide similar or better control for nonroad diesel engines designed to comply with the proposed Tier 4 standards.

4.1.3.1.3 Power Density Trends in Nonroad

An analysis of power density trends in nonroad diesel engines was undertaken in order to understand what levels of power density to expect in the future for nonroad diesel engines. For this analysis, data from Power Systems Research 2002 database (PSR) was examined. The PSR data includes estimates of nonroad diesel engine model specifications and sales going back at least 20 years. This data set represents the most comprehensive nonroad engine database of this nature available.

This analysis specifically examined trends in power density within a number of power categories from 1985 to 2000. The PSR database reports both rated power and engine displacement, from which power was calculated[K]. The data was divided into 5 power categories: 70-100 hp; 100 - 175hp; 175 - 300hp, 300 - 600hp, and >600hp. For each power category, a sales weighted average of power density was calculated for each year. Table 4.1-15 shows the resulting data, as well as the percent change from 1985 to 2000. Figure 4.1-17 is a graphical representation of the data in Table 4.1-15.

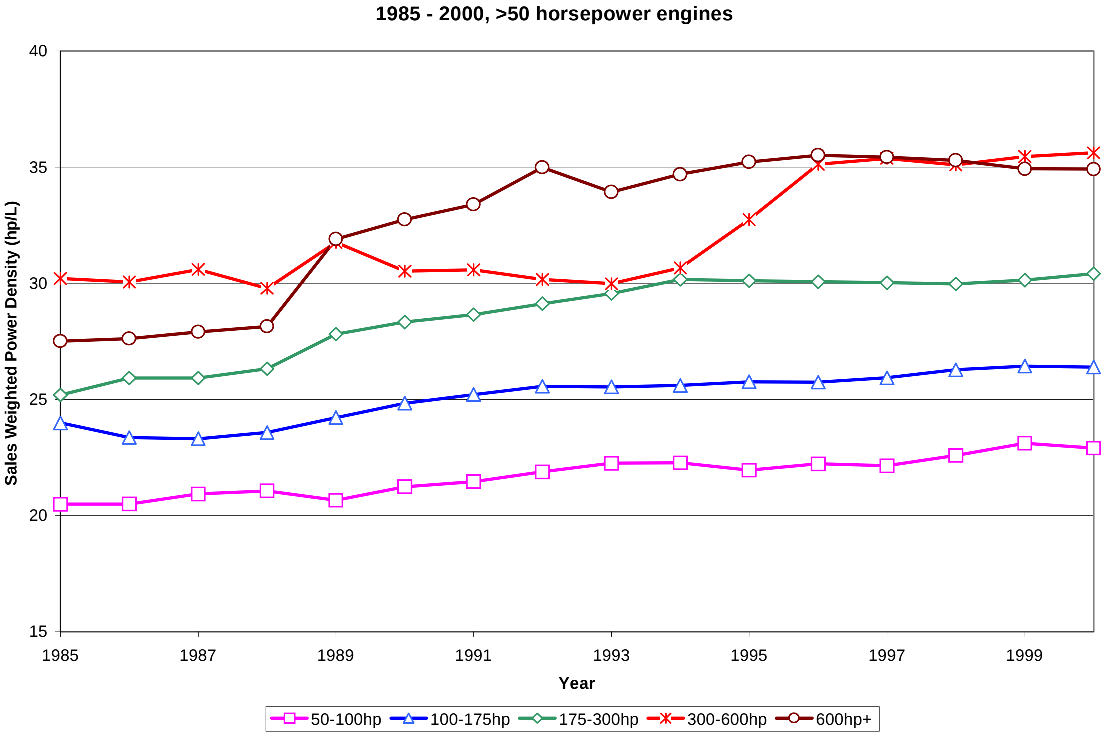
[K] Power density is equal to the engine's rated power divided by the engines total displacement. The data in this memorandum is presented in terms of horsepower/liter.

Table 4.1-15
Sales Weighted Power Density, 1985 - 2000

	Sales Weighted Power Density by Power Category (hp/liter)				
Year	50-100hp	100-175hp	175-300hp	300-600hp	600hp+
1985	20.5	24.0	25.2	30.2	27.5
1986	20.5	23.4	25.9	30.1	27.6
1987	20.9	23.3	25.9	30.6	27.9
1988	21.1	23.6	26.3	29.8	28.1
1989	20.7	24.2	27.8	31.8	31.9
1990	21.2	24.8	28.3	30.5	32.7
1991	21.5	25.2	28.7	30.6	33.4
1992	21.9	25.6	29.1	30.2	35.0
1993	22.3	25.5	29.6	30.0	33.9
1994	22.3	25.6	30.2	30.7	34.7
1995	22.0	25.8	30.1	32.7	35.2
1996	22.2	25.7	30.1	35.1	35.5
1997	22.1	25.9	30.0	35.4	35.4
1998	22.6	26.3	30.0	35.1	35.3
1999	23.1	26.4	30.1	35.5	34.9
2000	22.9	26.4	30.4	35.6	34.9
% Change 1985 - 2000	11%	9%	17%	15%	21%

Figure 4.1-7 shows reasonably steady increase in power density for engines all power categories from 1985 until approximately 1994/1995, though the rate of increase varies between the power categories. From 1994/95 until 2000 most power categories saw either no change or a slight increase in power density, with the exception of the >600hp category, which saw a small decrease. Power density increases by engine rated power, with the 70-100hp category showing the lowest values, with year 2000 being 22.9 hp/liter, and the 300-600hp and 600+hp categories have sales weighted power densities on the order of 35 hp/liter.

Figure 4.1-17 Power Density Trends for Nonroad Diesel Engines



4.1.3.2 Durability and Design

Nonroad equipment is designed to be used in a wide range of tasks in some of the harshest operating environments imaginable, from mining equipment to crop cultivation and harvesting to excavation and loading. In the normal course of equipment operation the engine and its associated hardware will experience levels of vibration, impacts, and dust that may exceed conditions typical of on-highway diesel vehicles. If no consideration is given to differences in operating conditions in engine and equipment design eventual failure of the equipment would be expected.

Specific efforts to design for the nonroad operating conditions will be required in order to ensure that the benefits of these new emission control technologies are realized for the life of nonroad equipment. Much of the engineering knowledge and experience to address these issues already exists with the nonroad equipment manufacturers. Vibration and impact issues are fundamentally mechanical durability concerns (rather than issues of technical feasibility of achieving emissions reductions) for any component mounted on a piece of equipment (e.g., an engine coolant overflow tank). Equipment manufacturers must design mounting hardware such as flanges, brackets, and bolts to support the new component without failure. Further, the catalyst substrate material itself must be able to withstand the conditions encountered on nonroad equipment without itself cracking or failing. There is a large body of real world testing with retrofit emission control technologies that demonstrates the durability of the catalyst components themselves even in the harshest of nonroad equipment applications.

Deutz, a nonroad engine manufacturer, sold approximately 2,000 diesel particulate filter systems for nonroad equipment in the period from 1994 through 2000. Many of these systems were sold for use in mining equipment. No other applications are likely to be more demanding than this. Mining equipment is exposed to extraordinarily high levels of vibration, experiences impacts with the mine walls and face, and high levels of dust. Yet in meetings with the Agency, Deutz shared their experience that no system had failed due to mechanical failure of the catalyst or catalyst housing.[104] The Deutz system utilized a conventional cordierite PM filter substrate as is commonly used for heavy-duty on-highway truck CDPF systems. The canning and mounting of the system was a Deutz design. Deutz was able to design the catalyst housing and mounting in such a way as to protect the catalyst from the harsh environment as evidenced by its excellent record of reliable function.

Other nonroad equipment manufacturers have also offered OEM diesel particulate filter systems in order to comply with requirements of some mining and tunneling worksite standards. Liebherr, a nonroad engine and equipment manufacturer, offers diesel particulater filter systems as an OEM option on 340 different nonroad equipment models.[105] We believe that this experience shows that appropriate design considerations, as are necessary with any component on a piece of nonroad equipment, will be adequate to address concerns with the vibration and impact conditions which can occur in some nonroad applications. This experience applies equally well to the NOx adsorber catalyst technologies as the mechanical properties of DOCs, CDPFs, and NOx adsorbers are all similar. We do not believe that any new or fundamentally different solutions will need to be invented in order to address the vibration and impact constraints for nonroad equipment. Our cost analysis includes the hardware costs for mounting and shielding the aftertreatment equipment as well as the engineering cost for equipment redesign.

Certain nonroad applications, including some forms of harvesting equipment and mining equipment, may have specific limits on maximum surface temperature for equipment components in order to ensure that the components do not serve as ignition sources for flammable dust particles (e.g. coal dust or fine crop dust). Some have suggested that these design constraints might limit the equipment manufacturers ability to install advanced diesel catalyst technologies such as NOx adsorbers and CDPFs. This concern seems to be largely based upon anecdotal experience with gasoline catalyst technologies where under certain circumstances catalyst temperatures can exceed 1,000˚C and without appropriate design considerations could conceivably serve as an ignition source. We do not believe that these concerns are justified in the case of either the NOx adsorber catalyst or the CDPF technology. Catalyst temperatures for NOx adsorbers and CDPFs should not exceed the maximum exhaust manifold temperatures already commonly experienced by diesel engines (i.e, catalyst temperatures are expected to be below 800˚C).[L] CDPF temperatures are not expected to exceed approximately 700˚C in normal use and are expected to only reach the 650˚C temperature during periods of active regeneration. Similarly, NOx adsorber catalyst temperatures are not expected to exceed 700˚C and again only during periods of active sulfur regeneration as described in Section 4.F below. Under conditions where diesel exhaust temperatures are naturally as high as 650˚C, no supplemental heat addition from the emission control system will be necessary and therefore exhaust temperatures will not exceed their natural level. When natural exhaust temperatures are too low for effective emission system function then supplemental heating as described earlier may be necessary but would not be expected to produce temperatures higher than the maximum levels normally

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[L] The hottest surface on a diesel engine is typically the exhaust manifold which connects the engines exhaust ports to the inlet of the turbocharger. The hot exhaust gases leave the engine at a very high temperature (800˚C at high power conditions) and then pass through the turbo where the gases expand driving the turbocharger providing work and are cooled in the process. The exhaust leaving the turbocharger and entering the catalyst and the remaining pieces of the exhaust system is normally at least 100˚C cooler than in the exhaust manifold.

encountered in diesel exhaust. Furthermore, even if it were necessary to raise exhaust temperatures to a higher level in order to promote effective emission control, there are technologies available to isolate the higher exhaust temperatures from flammable materials such as dust. One approach would be the use of air-gapped exhaust systems (i.e., an exhaust pipe inside another concentric exhaust pipe separated by an air-gap) that serve to insulate the inner high temperature surface from the outer surface which could come into contact with the dust. The use of such a system may be additionally desirable in order to maintain higher exhaust temperatures inside the catalyst in order to promote better catalyst function. Another technology to control surface temperature already used by some nonroad equipment manufacturers is water cooled exhaust systems.[106] This approach is similar to the air-gapped system but uses engine coolant water to actively cool the exhaust system. We do not believe that flammable dust concerns will prevent the use of either a NOx adsorber or a CDPF because catalyst temperatures are not expected to be unacceptably high and because remediation technologies exist to address these concerns. In fact, exhaust emission control technologies (i.e., aftertreatment) have already been applied on both an OEM basis and for retrofit to nonroad equipment for use in potentially explosive environments. Many of these applications must undergo Underwriters Laboratory (UL) approval before they can be used. [107]

We agree that nonroad equipment must be designed to address durable performance for a wide range of operating conditions and applications that would not commonly be experienced by on-highway vehicles. We believe further as demonstrated by retrofit experiences around the world that technical solutions exist which allow catalyst based emission control technologies to be applied to nonroad equipment.

4.1.4 Are the Standards Proposed for Engines >25 hp and <75 hp Feasible?

As discussed in Section III of the preamble, our proposal for standards for engines between 25 and 75 hp consists of a 2008 transitional standard and long-term 2013 standards. The proposed transitional standard is a 0.22 g/bhp-hr PM standard. The 2013 standards consist of a 0.02 g/bhp-hr PM standard and a 3.5 g/bhp-hr NMHC+NOx standard. The transitional standard is optional for 50-75 hp engines, as the proposed 2008 implementation date is the same as the effective date of the Tier 3 standards. Manufactures may decided, at their option, not to undertake the 2008 transitional PM standard, in which case their implementation date for the 0.02 g/bhp-hr PM standard begins in 2012.

In addition, we have proposed a minor revision to the CO standard for the 25-50 hp engines beginning in 2008 to align these engines with the 50-75 hp engines. This proposed CO standard is 3.7 g/bhp-hr.

The remainder of this section discusses:

- what makes the 25-75 hp category unique;
- what engine technology is used today, and will be used for applicable Tier 2 and Tier 3 standards; and,
- why the proposed standards are technologically feasible.

4.1.4.1 What makes the 25 - 75 hp category unique?

Many of the nonroad diesel engines ≥75 hp are either a direct derivative of highway heavy-duty diesel engines, or share a number of common traits with highway diesel engines. These include similarities in displacement, aspiration, fuel systems, and electronic controls. Table 4.1-16 contains a summary of a number of key engine parameters from the 2001 engines certified for sale in the U.S.[M]

Table 4.1-16
Summary of Model Year 2001 Key Engine Parameters by Power Category

Engine Parameter	Percent of 2001 U.S. Production[a]			
	0-25 hp	25-75 hp	75-100 hp	>100 hp
IDI Fuel System	83%	47%	4%	<0.1%
DI Fuel System	17%	53%	96%	>99%
Turbocharged	0%	7%	62%	91%
1 or 2 Cylinder Engines	47%	3%	0%	0%
Electronic fuel systems (estimated)	not available today	limited availability today	available today	commonly available today

[a] Based on sales weighting of 2001 engine certification data

As can be seen in Table 4.1-16, the engines in the 25-75 hp category have a number of technology differences from the larger engines. These include a higher percentage of indirect-injection fuel systems, and a low fraction of turbocharged engines. (The distinction in the <25 hp category is quite different, with no turbocharged engines, nearly one-half of the engines have two cylinders or less, and a significant majority of the engines have indirect-injection fuel systems.)

The distinction is particularly marked with respect to electronically controlled fuel systems. These are commonly available in the $\geq$ 75 hp power categories, but, based on the available certification data as well as our discussions with engine manufacturers, we believe there are very limited, if any in the 25-75 hp category (and no electronic fuel systems in the less than 25 hp category). The research and development work being performed today for the heavy-duty highway market is targeted at engines which are 4-cylinders or more, direct-injection, electronically controlled, turbocharged, and with per-cylinder displacements greater than 0.5 liters. As discussed in more detail below, as well as in Section 4.1.5.1 (regarding the <25 hp category), these engine distinctions are important from a technology perspective and warrant a different set of standards for the 25-75 hp category (as well as for the <25 hp category).

4.1.4.2 What engine technology is used today, and will be used for Tier 2 and Tier 3?

In the 1998 nonroad diesel rulemaking, we established Tier 1 and Tier 2 standards for engines in the 25-50 hp category. Tier 1 standards were implemented in 1999, and the Tier 2 standards take effect in 2004. The 1998 rule also established Tier 2 and Tier 3 standards for engines between 50 and 75 hp. The Tier 2 standards take effect in 2004, and the Tier 3 standards take effect in 2008. The Tier 1 standards for engines between 50 and 75 hp took effect in 1998. Therefore, all engines in the

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[M] Data in Table 4.1-16 is derived from a combination of the publically available certification data for model year 2001 engines, as well as the manufacturers reported estimates of 2001 production targets, which is not public information.

25-75 hp range have been meeting Tier 1 standards for the past several years, and the data presented in Table 4.1-17 represent performance of Tier 1 technology for this power range.

Engines in the 25-75 hp category use either indirect injection (IDI) or direct injection (DI) fuel systems. The IDI system injects fuel into a pre-chamber rather than directly into the combustion chamber as in the DI system.[108] This difference in fuel systems results in substantially different emission characteristics, as well as several important operating parameters. In general, the IDI engine has lower engine-out PM and NOx emissions, while the DI engine has better fuel efficiency and lower heat rejection.[109]

We expect a significant shift in the engine technology which will be used in this power category as a result of the upcoming Tier 2 and Tier 3 standards, in particular for the 50-75 hp engines. In the 50-75 hp category, the 2008 Tier 3 standards will likely result in the significant use of turbocharging and electronic fuel systems, as well as the introduction of both cooled and uncooled exhaust gas recirculation by some engine manufacturers and possibly the use of charge-air-cooling.[110] In addition, we have heard from some engine manufactures that the engine technology used to meet Tier 3 for engines in the 50-75 hp range will also be made available on those engines in the 25-50 hp range which are built on the same engine platform. For the Tier 2 standards for the 25-50 hp products, a large number of engines meet these standards today, and therefore we expect to see only moderate changes in these engines, including the potential additional use of turbocharging on some models.[111]

4.1.4.3 Are the proposed standards for 25 -75 hp engines technologically feasible?

This section will discuss the feasibility of both the proposed interim 2008 PM standard and the long-term 2013 standards.

4.1.4.3.1 2008 PM Standards

As just discussed in Section 4.1.4.2, engines in the 25-50 hp category must meet Tier 1 NMHC+NOx and PM standards today. We have examined the model year 2002 engine certification data for engines in the 25-50 hp category.[112] A summary of this data is presented in Table 4.1-17. These data indicate that over 10 percent of the engine families meet the proposed 2008 0.22 g/bhp-hr PM standard and 5.6 g/bhp-hr NMHC+NOx standard (unchanged from Tier 2 in 2008) today. These include a variety of engine families using a mix of engine technologies (IDI and DI, turbocharged and naturally aspirated) tested on a variety of certification test cycles.[N] Five engine families are more than 20 percent below the proposed 0.22 g/bhp-hr PM standard, and an additional 24 engine families which already meet the 2008 NMHC+NOx standards would require no more than a 30 percent PM reduction to meet the proposed 2008 PM standards. Unfortunately, similar data do not exist for engines between 50 and 75 hp. There is no Tier 1 PM standard for engines in this power range, and therefore engine manufacturers are not required to report PM emission levels until Tier 2 starts in 2004. However, in general, the 50-75 hp engines are more technologically advanced than the smaller horsepower engines and would be expected to perform as well as, if not better than, the engines in the 25 - 50 hp range.

[N] The Tier 1 standards for this power category must be demonstrated on one of a variety of different engine test cycles. The appropriate test cycle is selected by the engine manufacturer based on the intended in-use application of the engine.

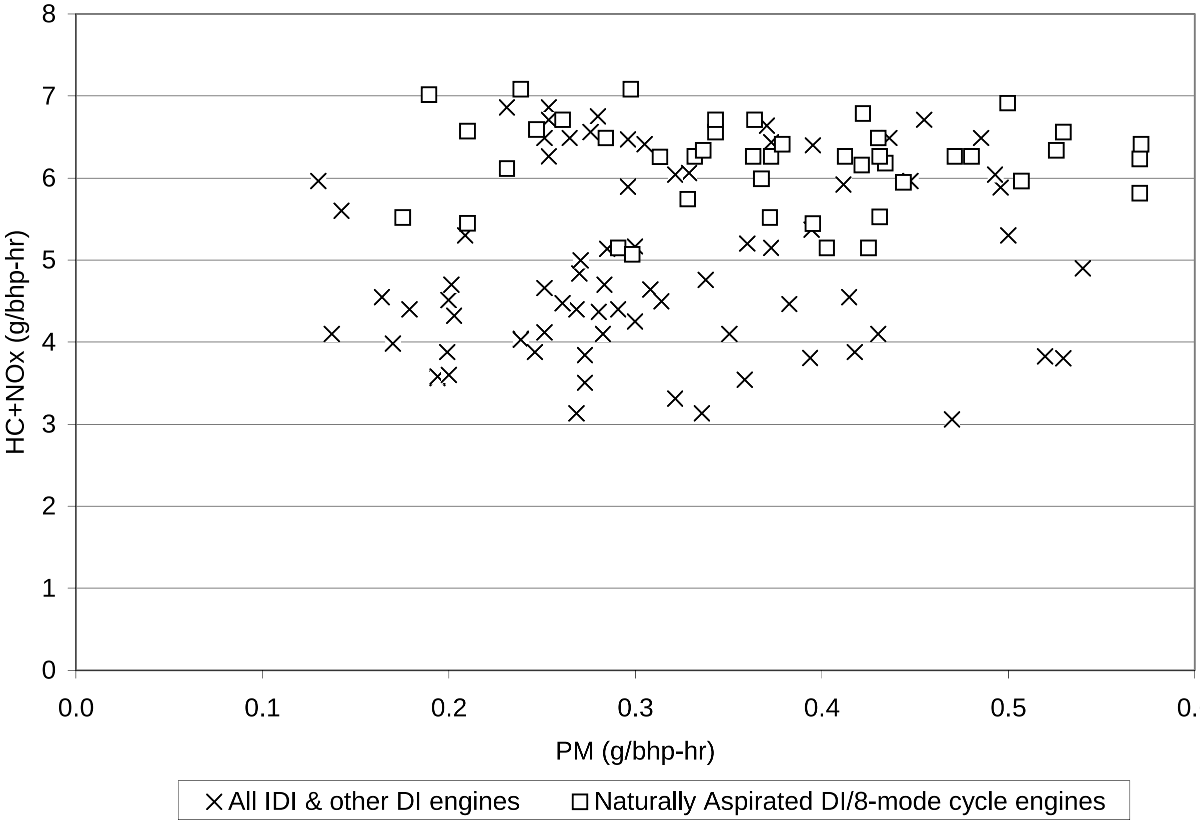
Table 4.1-17
2002 Model Year Certification Data for 25-50 hp Nonroad Diesel Engines

PM Emissions Relative to Proposed 0.22 g/bhp-hr Standard	IDI Engines (test cycle/aspiration)				DI Engines (test cycle/aspiration)			Totals
	5-mode/ NA	8-mode/ NA	5-mode/ TC	8-mode/ TC	5-mode/ NA	8-mode/ NA	8-mode/ TC	
0 - 5 % below T4[a]	0	0	0	0	0	1	0	1
5 - 20 % below T4[a]	1	5	1	2	0	0	0	9
>20 % below T4[a]	2	1	0	1	0	1	0	5
require ≤30% PM reduction to meet T4[a]	3	15	0	4	0	2	0	24
requires >30%PM reduction and/or > 2008 NMHC+NOx std.	2	17	1	3	8	40	8	79
Total # of Engine Families	8	38	2	10	8	44	8	118

[a] Engine also meets 2008 NMHC+NOx

The model year 2002 engines in this power range use well known engine-out emission control technologies, such as optimized combustion chamber design and fuel injection timing control strategies, to comply with the existing standards. These data have a two-fold significance. First, they indicate that a number of engines in this power range can already achieve the proposed 2008 standard for PM using only engine-out technology, and that other engines should be able to achieve the standard making improvements just to engine-out performance. Despite being certified to the same emission standards with similar engine technology, the emission levels from these engines vary widely. Figure 4.1-18 is a graph of the model year 2002 HC+NOx and PM data for engines in the 25-50 hp range. As can be seen in Figure 4.1-18, the emission levels cover a wide range. The figure highlights a specific example of this wide range: engines using naturally aspirated DI technology and tested on the 8-mode test cycle. Even for this subset of DI engines achieving approximately the same HC+NOx level of ~6.5 g/bhp-hr, the PM rates vary from approximately 0.2 to more than 0.5 g/bhp-hr. There is limited information available to indicate why for these small diesel engines with similar technology operating at approximately the same HC+NOx level the PM emission rates cover such a broad range. We are therefore not predicating the proposed 2008 PM standard on the combination of diesel oxidation catalysts and the lowest engine-out emissions being achieved today, because it is uncertain whether or not additional engine-out improvements would lower all engines to the proposed 2008 PM standard. Instead, we believe there are two likely means by which companies can comply with the proposed 2008 PM standard. First, some engine manufacturers can comply with this standard using known engine-out techniques (e.g., optimizing combustion chamber designs, fuel-injection strategies). However, based on the available data it is unclear whether engine-out techniques will work in all cases. Therefore, we believe some engine companies will choose to use a combination of engine-out techniques and diesel oxidation catalysts, as discussed below.

Figure 4.1-18 Emission Certification Data for 25-50 HP Model Year 2002 Engines



For those engines which do not already meet the proposed 2008 Tier 4 PM standard, a number of engine-out technologies are available to achieve the standards by 2008. In our recent Staff Technical Paper on the feasibility of the Tier 2 and Tier 3 standards, we projected that in order to comply with the Tier 3 standards, engines greater than 50 hp would rely on some combination of a number of technologies, including electronic fuel systems such as electronic rotary pumps or common-rail fuel systems.[113] In addition to enabling the Tier 3 NMHC+NOx standards, electronic fuel systems with high injection pressure and the capability to perform pilot-injection and rate-shaping, have the potential to substantially reduce PM emissions.[114] Even for mechanical fuel systems, increased injection pressures can reduce PM emissions substantially.[115] As discussed above, we are projecting that the Tier 3 engine technologies used in engines between 50 and 75 hp, such as turbocharging and electronic fuel systems, will make their way into engines in the 25-50 hp range. However, we do not believe this technology will be required to achieve the proposed 2008 PM standard. As demonstrated by the 2002 certification data, engine-out techniques such as optimized combustion chamber design, fuel injection pressure increases and fuel injection timing can be used to achieve the proposed standards for many of the engines in the 25-75 hp category without the need to add turbocharging or electronic fuel systems.

For those engines which are not able to achieve the proposed standards with known engine-out techniques, we project that diesel oxidation catalysts can be used to achieve the proposed standards. DOCs are passive flow-through emission control devices which are typically coated with a precious metal or a base-metal washcoat. DOCs have been proven to be durable in use on both light-duty and heavy-duty diesel applications. In addition, DOCs have already been used to control PM or carbon monoxide on some nonroad applications.[116]

Certain DOC formulations can be sensitive to diesel fuel sulfur levels, and depending on the level of emission reduction necessary, sulfur in diesel fuel can be an impediment to PM reductions. Precious metal oxidation catalysts can oxidize the sulfur in the fuel and form particulate sulfates. However, even with today's high sulfur nonroad fuel, some manufacturers have demonstrated that a properly formulated DOC can be used in combination with other technologies to achieve the existing Tier 2 PM standards for larger engines (i.e., the 0.15 g/bhp-hr standard).[117] However, given the high level of sulfur in nonroad fuel today, the use of DOCs as a PM reduction technology is severely limited. Data presented by one engine manufacturer regarding the existing Tier 2 PM standard shows that while a DOC can be used to meet the current standard even when tested on 2,000 ppm sulfur fuel, lowering the fuel sulfur level to 380 ppm enabled the DOC to reduce PM by 50 percent from the 2,000 ppm sulfur fuel.[118] Without the availability of 500 ppm sulfur fuel in 2008, DOCs would be of limited use for nonroad engine manufacturers and would not provide the emissions necessary to meet the proposed standards for most engine manufacturers. With the availability of 500 ppm sulfur fuel, DOC's can be designed to provide PM reductions on the order of 20 to 50%, while suppressing particulate sulfate reduction.[119] These levels of reductions have been seen on transient duty cycles as well as highway and nonroad steady-state duty cycles. As discussed above, 24 engine families in the 25-50 hp range are within 30 percent of the proposed 2008 PM standard and are at or below the 2008 NMHC+NOx standard for this power range, indicating that use of DOCs should readily achieve the incremental improvement necessary to meet the proposed 2008 PM standard.

As discussed in Section III of the preamble, we have also proposed a minor change in the CO standard for the 25-50 hp engines, in order to align it with the standard for the 50-75 hp engines. This small change in the CO standard is intended to simplify EPA's regulations as part of our decision to propose a reduction in the number of engine power categories for Tier 4. The current CO standard for this category is 4.1 g/bhp-hr, and the proposed standard is 3.7 g/bhp-hr (i.e., the current standard for engines in the 50-75 hp range). The model year 2002 certification data shows that more than 95 percent of the engine families in the 25-50 hp engine range meet the proposed CO standard today. In addition, a recent EPA test program run by a contractor on two nonroad diesel engines in this power range showed that CO emissions were well below the proposed standards not only when tested on the existing steady-state 8-mode test procedure, but also when tested on the nonroad transient duty cycle we are proposing in today's action.[120] Finally, DOCs typically reduce CO emissions on the order of 50 percent or more, on both transient and steady-state duty cycles.[121] Given that more than 95 percent of the engines in this category meet the proposed standard today, and the ready availability of technology which can easily achieve the proposed standard, we project this CO standard will be achievable by model year 2008.

4.1.4.3.2 2013 Standards

For engines in the 25-50 range, we are proposing standards commencing in 2013 of 3.5 g/bhp-hr for NMHC+NOx and 0.02 g/bhp-hr for PM. For the 50-75 hp engines, we are proposing a 0.02 g/bhp-hr PM standard which will be implemented in 2013, and for those manufacturers who choose to pull-ahead the standard one-year, 2012 (manufacturers who choose to pull-ahead the 2013 standard for engine in the 50-75 range do not need to comply with the transitional 2008 PM standard).

4.1.4.3.2.1 PM Standard

Sections 4.1.1 through 4.1.3 have already discussed catalyzed diesel particulate filters, including explanations of how CDPFs reduce PM emissions, and how to apply CDPFs to nonroad engines. We concluded there that CDPFs can be used to achieve the proposed PM standard for engines $\geq$75 hp. As also discussed in Section 4.1.3, PM filters may require active back-up regeneration systems for many nonroad applications. A number of secondary technologies are likely required to enable proper regeneration, including possibly electronic fuel systems such as common rail systems which are capable of multiple post-injections which can be used to raise exhaust gas temperatures to aid in filter regeneration.

Particulate filter technology, with the requisite trap regeneration technology, can also be applied to engines in the 25 to 75 hp range. The fundamentals of how a filter is able to reduce PM emissions as described in Section 4.1.1, are not a function of engine power, and CDPF's are just as effective at capturing soot emissions and oxidizing SOF on smaller engines as on larger engines. As discussed in more detail below, particulate sulfate generation rates are slightly higher for the smaller engines, however, we have addressed this issue in our proposal. The PM filter regeneration systems described in 4.1.1 and 4.1.3 are also applicable to engines in this size range and are therefore likewise feasible. There are specific trap regeneration technologies which we believe engine manufacturers in the 25-75 hp category may prefer over others. Specifically, an electronically-controlled secondary fuel injection system (i.e., a system which injects fuel into the exhaust upstream of a PM filter). Such a system has been commercially used successfully by at least one nonroad engine manufacturer, and other systems have been tested by technology companies.[122]

We are, however, proposing a slightly higher PM standard (0.02 g/bhp-hr rather than 0.01) for these engines. As discussed in Section 4.1.1, with the use of a CDPF, the PM emissions emitted by the filter are primarily derived from the fuel sulfur. The smaller power category engines tend to have higher fuel consumption than larger engines. This occurs for a number of reasons. First, the lower power categories include a high fraction of IDI engines which by their nature consume approximately 15 percent more fuel than a DI engine. Second, as engine displacements get smaller, the engine's combustion chamber surface-to-volume ratio increases. This leads to higher heat-transfer losses and therefor lower efficiency and higher fuel consumption. In addition, frictional losses are a higher percentage of total power for the smaller displacement engines which also results in higher fuel consumption. Because of the higher fuel consumption rate, we expect a higher particulate sulfate level, and therefore we have proposed a 0.02 g/bhp-hr standard.

Test data confirm that this proposed standard, as well as the proposed NTE of 1.5 times the standard, are achievable. In 2001, EPA completed a test program run by a contractor on two small nonroad diesel engines (a 25 hp IDI engine and a 50 hp IDI engine) which demonstrated the proposed 0.02 g/bhp-hr standard can be achieved with the use of a CDPF.[123] This test program included testing on the existing 8-mode steady-state test cycle as well as the nonroad transient cycle proposed in today's action. The 0.02g/bhp-hr level was achieved on each engine over both test cycles. In addition, the 0.02 g/bhp-hr level was achieved on a variety of nonroad test cycles which are intended to represent several specific applications, such as skid-steer loaders, arc-welders, and agricultural tractors. We believe these data are indicative of the robust emission reduction capability of particulate filters and demonstrates the proposed NTE standard of 1.5 x 0.02 g/bhp-hr standard (0.03 g/bhp-hr) can be achieved using the proposed not-to-exceed test requirements. This test program also demonstrates why EPA has proposed a slightly higher PM standard for the 25 - 75 hp category (0.02 g/bhp-hr vs 0.01). The data from the test program described above showed fuel consumption rates over the 8-mode test procedure between 0.4 and 0.5 lbs/bhp-hr, while typical values for a modern turbocharged DI engine with 4-valves per cylinder in the ≥75 hp categories are on the order of 0.3 to 0.35 lbs/hp-hr.

4.1.4.3.2.2 NMHC+NOx Standard

We have proposed a 3.5 g/bhp-hr NMHC+NOx standard for engines in the 25 - 50 hp range for 2013. This will align the NMHC+NOx standard for engines in this power range with the Tier 3 standard for engines in the 50 - 75 hp range which are implemented in 2008. EPA's recent Staff Technical paper which reviewed the technological feasibility of the Tier 3 standards contains a detailed discussion of a number of technologies which are capable of achieving a 3.5 g/bhp-hr standard. These include cooled EGR, uncooled EGR, as well as advanced in-cylinder technologies relying on electronic fuel systems and turbocharging.[124] These technologies are capable of reducing NOx emission by as much as 50 percent. Given the Tier 2 NMHC+NOx standard of 5.6 g/bhp-hr, a 50 percent reduction would allow a Tier 2 engine to comply with the 3.5 g/bhp-hr NMHC+NOx standard proposed in this action. In addition, because this NMHC+NOx standard is concurrent with the 0.02 g/bhp-hr PM standards which we project will be achievable with the use of particulate filters, engine designers will have significant additional flexibility in reducing NOx because the PM filter will eliminate the traditional concerns with the engine-out NOx vs. PM trade-off.

4.1.5 Are the Standards Proposed for Engines <25 hp Feasible?

As discussed in Section III of the preamble, our proposal for standards for engines less than 25 hp is a new PM standard of 0.30 g/bhp-hr beginning in 2008. As discussed below, we are not proposing to set a new standard more stringent than the existing Tier 2 NMHC+NOx standard for this power category at this time. This section describes:

- what makes the <25 hp category unique;
- engine technology currently used in the <25 hp category; and,
- what data shows the proposed standards are technologically feasible.

4.1.5.1 What makes the < 25 hp category unique?

Nonroad engines less than 25 hp are the least sophisticated nonroad diesel engines from a technological perspective. All of the engines currently sold in this power category lack electronic fuel systems and turbochargers (see Table 4.1-16). Nearly 50 percent of the products have two-cylinders or less, and 14 percent of the engines sold in this category are single-cylinder products, a number of these have no batteries and are crank-start machines, much like today's simple walk behind lawnmower engines. In addition, given what we know today and taking into account the Tier 2 standards which have not yet been implemented, we are not projecting any significant penetration of advanced engine technology, such as electronically controlled fuel systems, into this category in the next 5 to 10 years.

4.1.5.2 What engine technology is currently used in the <25 hp category?

In the 1998 nonroad diesel rulemaking we established Tier 1 and Tier 2 standards for these products. Tier 1 was implemented in model year 2000, and Tier 2 will be implemented in model year 2005. As discussed in EPA's recent Staff Technical Paper, we project the Tier 2 standards will be met by basic engine-out emission optimization strategies.[125] We are not predicting that Tier 2 will require electronic fuel systems, EGR, or turbocharging. As discussed in the Staff Technical Paper, a large number of engines in this power category already meet the Tier 2 standards by a wide margin.[126]

Two basic types of engine fuel injection technologies are currently present in the less than 25 hp category, mechanical indirect injection (IDI) and mechanical direct injection (DI). The IDI system injects fuel into a pre-chamber rather than directly into the combustion chamber as in the DI system. This difference in fuel systems results in substantially different emission characteristics, as well as several important operating parameters. In general, as noted earlier, the IDI engine has lower engine-out PM and NOx emissions, while the DI engine has better fuel efficiency and lower heat rejection.

4.1.5.3 What data indicates the proposed standards are feasible?

We project the proposed Tier 4 PM standard can be met by 2008 based on:
—the existence of a large number of engine families which meet the proposed standards today;
—the use of engine-out reduction techniques; and
—the use of diesel oxidation catalysts.

We have examined the recent model year (2002) engine certification data for nonroad diesel engines less than 25 hp category.[127] A summary of this data is presented in Table 4.1-18 These data indicate that a number of engine families meet the proposed Tier 4 PM standard (and the 2008 NMHC+NOx standard, unchanged from Tier 2) today. The current data indicates approximately 28% of the engine families are at or below the proposed PM standard today, while meeting the 2008 NMHC+NOx standard. These include both IDI and DI engines, as well as a range of certification test cycles.[O] Many of the engine families are certified well below the proposed Tier 4 standard while meeting the 2008 NMHC+NOx level. Specifically, 15 percent of the engine families are more than 20 percent below the proposed Tier 4 PM standard. An additional 15 percent of the engine families which already meet the 2008 NMHC+NOx standards would require no more than a 30 percent PM reduction to meet the proposed 2008 PM standards. The public certification data indicate that these engines do not use turbocharging, electronic fuel systems, exhaust gas recirculation, or aftertreatment technologies.

Table 4.1-18
2002 Model Year Certification Data for <25 hp Nonroad Diesel Engines

	IDI Engines (test cycle)			DI Engines (test cycle)			
PM Emissions Relative to Proposed 0.30 g/bhp-hr Standard	5-mode	6-mode	8-mode	5-mode	6-mode	8-mode	Totals

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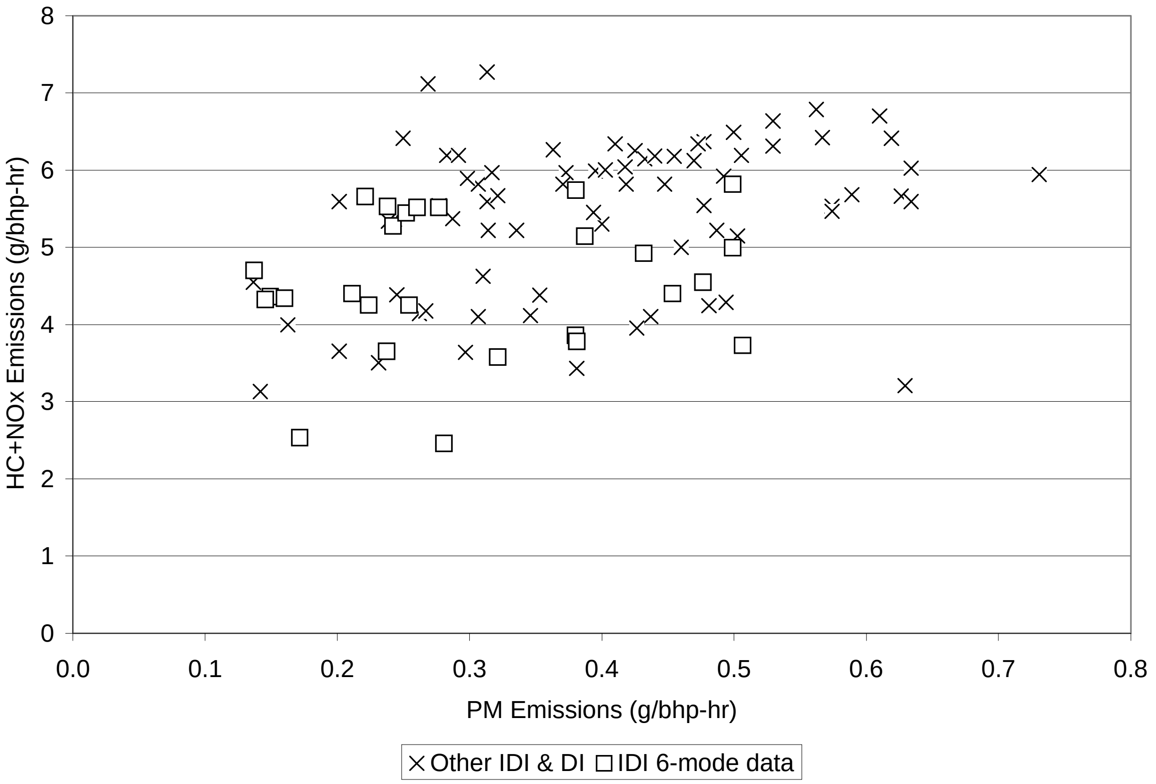
[O] The Tier 1 and Tier 2 standards for this power category must be demonstrated on one of a variety of different engine test cycles. The appropriate test cycle is selected by the engine manufacturer based on the intended in-use applications(s) of the engine.

0-5% below T4[a]	1	0	1	0	0	0	2
5-20% below T4[a]	4	6	1	0	0	0	11
>20% below T4[a]	1	9	5	0	1	0	16
require ≤30% PM reduction to meet T4[a]	5	4	4	0	2	0	15
requires >30%PM reduction and/or > 2008 NMHC+NOx std.	7	8	4	18	18	3	58
Total # of Engine Families	18	27	15	18	21	3	102

[a] Engine also meets 2008 NMHC+NOx

These model year 2002 engines use well known engine-out emission control technologies, such as combustion chamber design and fuel injection timing control strategies, to comply with the existing standards. As with 25-75 hp engines, these data have a two-fold significance. First, they indicate that a number of engines in this power category can already achieve the proposed 2008 standard for PM using only engine-out technology, and that other engines should be able to achieve the standard making improvements just to engine-out performance. Despite being certified to the same emission standards with similar engine technology, the emission levels from these engines vary widely. Figure 4.1-19 is a graph of the model year 2002 HC+NOx and PM data. As can be seen in the figure, the emission levels cover a wide range. Figure 4.1-19 highlights a specific example of this wide range: engines using naturally aspirated IDI technology and tested on the 6-mode test cycle. Even for this subset of IDI engines achieving approximately the same HC+NOx level of~4.5 g/bhp-hr, the PM rates vary from approximately 0.15 to 0.5 g/bhp-hr. There is limited information available to indicate why for these small diesel engines with similar technology operating at approximately the same HC+NOx level the PM emission rates cover such a broad range. We are therefore not predicating the proposed 2008 PM standard on the combination of diesel oxidation catalysts and the lowest engine-out emissions being achieved today, because it is uncertain whether or not additional engine-out improvements would lower all engines to the proposed 2008 PM standard. Instead, we believe there are two likely means by which companies can comply with the proposed 2008 PM standard. First, some engine manufacturers can comply with this standard using known engine-out techniques (e.g., optimizing combustion chamber designs, fuel-injection strategies). However, based on the available data it is unclear whether engine-out techniques will work in all cases. Therefore, we believe some engine companies will choose to use a combination of engine-out techniques and diesel oxidation catalysts, as discussed below.

Figure 4.1-19 Emission Certification Data for 25-50 HP Model Year 2002 Engines



PM emissions can be reduced through in-cylinder techniques for small nonroad diesel engines using similar techniques as used in larger nonroad and highway engines. As discussed in Section 4.1.1 there are a number of technologies which exist that can influence oxygen content and in-cylinder mixing (and thus lower PM emissions) including improved fuel injection systems and combustion system designs. For example, increased injection pressure can reduce PM emissions substantially.[128] The wide-range of emission characteristics present in the existing engine certification data is likely a result of differences in fuel systems and combustion chamber designs. For many of the engines which have higher emission levels, further optimization of the fuel system and combustion chamber can provide additional PM reductions.

Diesel oxidation catalysts (DOC) also offer the opportunity to reduce PM emissions from the engines in this power category. DOCs are passive flow through emission control devices which are typically coated with a precious metal or a base-metal wash-coat. DOCs have been proven to be durable in-use on both light-duty and heavy-duty diesel applications. In addition, DOCs have already been used to control either PM or in some cases carbon monoxide on some nonroad applications.[129] However, as discussed in Section 4.1.1, certain DOC formulations can be sensitive to diesel fuel sulfur level. Specifically, precious-metal based oxidation catalysts (which have the greatest potential for reducing PM) can oxidize the sulfur in the fuel and form particulate sulfates. Given the high level of sulfur in nonroad fuel today, the use of DOCs as a PM reduction technology is severely limited. Data presented by one engine manufacturer regarding the existing Tier 2 PM standard shows that while a DOC can be used to meet the current standard when tested on 2,000 ppm sulfur fuel, lowering the fuel sulfur level to 380 ppm enabled the DOC to reduce PM by 50 percent from the 2,000 ppm sulfur fuel.[130] Without the availability of 500 ppm sulfur fuel in 2008, DOCs would be of limited use for nonroad engine manufacturers and would not provide the emissions necessary to meet the proposed standards for most engine manufacturers. With the availability of 500 ppm sulfur fuel, DOC's can be designed to provide PM reductions on the order of 20 to 50%, while suppressing particulate sulfate reduction.[131] These levels of reductions have been seen on transient duty cycles as well as highway and nonroad steady-state duty cycles.

As discussed in Section III of the preamble, we have also proposed a minor change in the CO standard for the <11 hp engines, in order to align those standards with the standards for the 11-25 hp engines. The small change in the CO standard is intended to simplify EPA's regulations as part of our decision to propose a reduction in the number of engine power categories for Tier 4. The current CO standard for this category is 6.0 g/bhp-hr, and the proposed standard is 4.9 g/bhp-hr (i.e., the current standard for engines in the 11-25 hp range). The model year 2002 certification data shows that more than 90 percent of the engine families in this power category meet the proposed standards today. In addition, DOCs typically reduce CO emissions on the order of 50 percent or more.[132] Given that more than 90 percent of the engines in this category meet the proposed standard today, and the ready availability of technology which can easily achieve the proposed standard, we project this CO standard will be achievable by model year 2008.

4.1.6 Meeting the Crankcase Emissions Requirements

The most common way to eliminate crankcase emissions has been to vent the blow-by gases into the engine air intake system, so that the gases can be recombusted. Prior to the HD2007 rulemaking, we have required that crankcase emissions be controlled only on naturally aspirated diesel engines. We had made an exception for turbocharged diesel engines (both on-highway and nonroad) because of concerns in the past about fouling that could occur by routing the diesel particulates (including engine oil) into the turbocharger and aftercooler. However, this is an environmentally significant exception since most nonroad equipment over 75hp use turbocharged engines, and a single engine can emit over 100 pounds of NOx, NMHC, and PM from the crankcase over its lifetime.

Given the available means to control crankcase emissions, we eliminated this exception for highway engines in 2007 and are proposing to eliminate the exception for nonroad diesel engines as well. We anticipate that the diesel engine manufacturers will be able to control crankcase emissions through the use of closed crankcase filtration systems or by routing unfiltered blow-by gases directly into the exhaust system upstream of the emission control equipment. However, the proposed provision has been written such that if adequate control can be had without "closing" the crankcase then the crankcase can remain "open." Compliance would be ensured by adding the emission from the crankcase ventilation system to the emissions from the engine control system downstream of any emission control equipment.

We expect that in order to meet the stringent tailpipe emission standards set here, that manufacturers will have to utilize closed crankcase approaches as described here. Closed crankcase filtration systems work by separating oil and particulate matter from the blow-by gases through single or dual stage filtration approaches, routing the blow-by gases into the engine's intake manifold and returning the filtered oil to the oil sump. Oil separation efficiencies in excess of 90 percent have been demonstrated with production ready prototypes of two stage filtration systems.[133] By eliminating 90 percent of the oil that would normally be vented to the atmosphere, the system works to reduce oil consumption and to eliminate concerns over fouling of the intake system when the gases are routed through the turbocharger. Hatz, a nonroad engine manufacturer, currently has closed crankcase systems on many of its turbocharged engines.

4.1.7 Why Do We Need 15ppm Sulfur Diesel Fuel?

As stated earlier, we strongly believe that fuel sulfur control is critical to ensuring the success of NOx and PM aftertreatment technologies. In order to evaluate the effect of sulfur on diesel exhaust control technologies, we used three key factors to categorize the impact of sulfur in fuel on emission control function. These factors were efficiency, reliability, and fuel economy. Taken together these three factors lead us to believe that diesel fuel sulfur levels of 15 ppm will be required for the nonroad emission standards proposed here to be feasible. Brief summaries of these factors are provided below.

The **efficiency** of emission control technologies to reduce harmful pollutants is directly affected by sulfur in diesel fuel. Initial and long term conversion efficiencies for NOx, NMHC, CO and diesel PM emissions are significantly reduced by catalyst poisoning and catalyst inhibition due to sulfur. NOx conversion efficiencies with the NOx adsorber technology in particular are dramatically reduced in a very short time due to sulfur poisoning of the NOx storage bed. In addition, total PM control efficiency is negatively impacted by the formation of sulfate PM. As explained in the following sections, the CDPF, NOx adsorber, and urea SCR catalyst technologies described here have the potential to make significant amounts of sulfate PM under operating conditions typical of many nonroad engines. We believe that the formation of sulfate PM will be in excess of the total PM standard, unless diesel fuel sulfur levels are at or below 15 ppm. Based on the strong negative impact of sulfur on emission control efficiencies for all of the technologies evaluated, we believe that 15 ppm represents an upper threshold of acceptable diesel fuel sulfur levels.

Reliability refers to the expectation that emission control technologies must continue to function as required under all operating conditions for the life of the engine. As discussed in the following sections, sulfur in diesel fuel can prevent proper operation of both NOx and PM control technologies. This can lead to permanent loss in emission control effectiveness and even catastrophic failure of the systems. Sulfur in diesel fuel impacts reliability by decreasing catalyst efficiency (poisoning of the catalyst), increasing diesel particulate filter loading, and negatively impacting system regeneration functions. Among the most serious reliability concerns with sulfur levels greater than 15 ppm are those associated with failure to properly regenerate. In the case of the NOx adsorber, failure to regenerate the stored sulfur (desulfate) will lead to rapid loss of NOx emission control as a result of sulfur poisoning of the NOx adsorber bed. In the case of the diesel particulate filter, sulfur in the fuel reduces the reliability of the regeneration function. If regeneration does not occur, catastrophic failure of the filter could occur. It is only by the availability of low sulfur diesel fuels that these technologies become feasible.

Fuel economy impacts due to sulfur in diesel fuel affect both NOx and PM control technologies. The NOx adsorber sulfur regeneration cycle (desulfation cycle) can consume significant amounts of fuel unless fuel sulfur levels are very low. The larger the amount of sulfur in diesel fuel, the greater the adverse effect on fuel economy. As sulfur levels increase above 15 ppm, the adverse effect on fuel economy becomes more significant, increasing above one percent and doubling with each doubling of fuel sulfur level. Likewise, PM trap regeneration is inhibited by sulfur in diesel fuel. This leads to increased PM loading in the diesel particulate filter and increased work to pump exhaust across this restriction. With low sulfur diesel fuel, diesel particulate filter regeneration can be optimized to give a lower (on average) exhaust backpressure and thus better fuel economy. Thus, for both NOx and PM technologies the lower the fuel sulfur level the lower the operating costs of the vehicle.

4.1.7.1 Catalyzed Diesel Particulate Filters and the Need for Low Sulfur Fuel

CDPFs function to control diesel PM through mechanical filtration of the solid PM (soot) from the diesel exhaust stream and then oxidation of the stored soot (trap regeneration) and oxidation of the SOF. Through oxidation in the catalyzed diesel particulate filter the stored PM is converted to CO_2 and released into the atmosphere. Failure to oxidize the stored PM leads to accumulation in the trap, eventually causing the trap to become so full that it severely restricts exhaust flow through the device, leading to trap or vehicle failure.

Uncatalyzed diesel particulate filters require exhaust temperatures in excess of 650˚C in order for the collected PM to be oxidized by the oxygen available in diesel exhaust. That temperature threshold for oxidation of PM by exhaust oxygen can be decreased to 450˚C through the use of base metal catalytic technologies. For a broad range of operating conditions typical of in-use diesel engine operation, diesel exhaust can be significantly cooler than 400˚C. If oxidation of the trapped PM could be assured to occur at exhaust temperatures lower than 300˚C, then diesel particulate filters would be expected to be more robust for most applications and operating regimes. Oxidation of PM (regeneration of the trap) at such low exhaust temperatures can occur by using oxidants which are more readily reduced than oxygen. One such oxidant is NO_2.

NO_2 can be produced in diesel exhaust through the oxidation of the nitrogen monoxide (NO), created in the engine combustion process, across a catalyst. The resulting NO_2-rich exhaust is highly oxidizing in nature and can oxidize trapped diesel PM at temperatures as cool as 250˚C.[134] Some platinum group metals are known to be good catalysts to promote the oxidation of NO to NO_2. Therefore in order to promote more effective passive regeneration of the diesel particulate filters, significant amounts of platinum group metals (primarily platinum) are being used in the wash-coat formulations of advanced CDPFs. The use of platinum to promote the oxidation of NO to NO_2 introduces several system vulnerabilities affecting both the durability and the effectiveness of the CDPF when sulfur is present in diesel exhaust. (In essence, diesel engine exhaust temperatures are in a range necessitating use of precious metal catalysts in order to adequately regenerate the PM filter, but precious metal catalysts are in turn highly sensitive to sulfur in diesel fuel.) The two primary mechanisms by which sulfur in diesel fuel limits the robustness and effectiveness of CDPFs are inhibition of trap regeneration, through inhibition of the oxidation of NO to NO_2, and a dramatic loss in total PM control effectiveness due to the formation of sulfate PM. Unfortunately, these two mechanisms trade-off against one another in the design of CDPFs. Changes to improve the reliability of regeneration by increasing catalyst loadings lead to increased sulfate emissions and, thus, loss of PM control effectiveness. Conversely, changes to improve PM control by reducing the use of platinum group metals and, therefore, limiting “sulfate make” leads to less reliable regeneration. We believe the best means of achieving good PM emission control and reliable operation is to reduce sulfur in diesel fuel, as shown in the following subsections.

4.1.7.1.1 Inhibition of Trap Regeneration Due to Sulfur

The CDPF technology relies on the generation of a very strong oxidant, NO_2, to ensure that the carbon captured by the PM trap's filtering media is oxidized under the exhaust temperature range of normal operating conditions. This prevents plugging and failure of the PM trap. NO_2 is produced through the oxidation of NO in the exhaust across a platinum catalyst. This oxidation is inhibited by sulfur poisoning of the catalyst surface.[135] This inhibition limits the total amount of NO_2 available for oxidation of the trapped diesel PM, thereby raising the minimum exhaust temperature required to ensure trap regeneration. Without sufficient NO_2, the amount of PM trapped in the diesel particulate filter will continue to increase and can lead to excessive exhaust back pressure and low engine power.

The failure mechanisms experienced by diesel particulate filters due to low NO_2 availability vary significantly in severity and long term consequences. In the most fundamental sense, the failure is defined as an inability to oxidize the stored particulate at a rate fast enough to prevent net particulate accumulation over time. The excessive accumulation of PM over time blocks the passages through the filtering media, making it more restrictive to exhaust flow. In order to continue to force the exhaust through the now more restrictive filter, the exhaust pressure upstream of the filter must increase. This increase in exhaust pressure is commonly referred to as increasing "exhaust backpressure" on the engine.

The increase in exhaust backpressure represents increased work being done by the engine to force the exhaust gas through the increasingly restrictive particulate filter. Unless the filter is frequently cleansed of the trapped PM, this increased work can lead to reductions in engine performance and increases in fuel consumption. This loss in performance may be noted by the equipment operator in terms of sluggish engine response.

Full field test evaluations and retrofit applications of these catalytic trap technologies are occurring in parts of the United States and Europe where low sulfur diesel fuel is already available.[P] The experience gained in these field tests helps to clarify the need for low sulfur diesel fuel. In Sweden and some European city centers where below 10 ppm diesel fuel sulfur is readily available, more than 3,000 catalyzed diesel particulate filters have been introduced into retrofit applications without a single failure. Given the large number of vehicles participating in these test programs, the diversity of the vehicle applications which included intercity trains, airport buses, mail trucks, city buses and garbage trucks, and the extended time periods of operation (some vehicles have been operating with traps for more than 5 years and in excess of 300,000 miles), there is a strong indication of the robustness of this technology on 10 ppm low sulfur diesel fuel.[136] The field experience in areas where sulfur is capped at 50 ppm has been less definitive. In regions without extended periods of cold ambient conditions, such as the United Kingdom, field tests on 50 ppm cap low sulfur fuel have also been positive, matching the durability at 10 ppm, although sulfate PM emissions are much higher. However, field tests on 50 ppm fuel in Finland, where colder winter conditions are sometimes encountered (similar to many parts of the United States), showed a significant number of failures (~10 percent) due to trap plugging. This 10 percent failure rate has been attributed to insufficient trap regeneration due to fuel sulfur in combination with low ambient temperatures.[137] Other possible reasons for the high failure rate in Finland when contrasted with the Swedish

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[P] Through tax incentives 50 ppm cap sulfur fuel is widely available in the United Kingdom and 10 ppm sulfur fuel is available in Sweden and in certain European city centers.

experience appear to be unlikely. The Finnish and Swedish fleets were substantially similar, with both fleets consisting of transit buses powered by Volvo and Scania engines in the 10 to 11 liter range. Further, the buses were operated in city areas and none of the vehicles were operated in northern extremes such as north of the Arctic Circle.[138] Given that the fleets in Sweden and Finland were substantially similar, and given that ambient conditions in Sweden are expected to be similar to those in Finland, we believe that the increased failure rates noted here are due to the higher fuel sulfur level in a 50 ppm cap fuel versus a 10 ppm cap fuel.[Q]

Testing on an even higher fuel sulfur level of 200 ppm was conducted in Denmark on a fleet of 9 vehicles. In less than six months all of the vehicles in the Danish fleet had failed due to trap plugging.[139] The failure of some fraction of the traps to regenerate when operated on fuel with sulfur caps of 50 ppm and 200 ppm is believed to be primarily due to inhibition of the NO to NO_2 conversion as described here. Similarly the increasing frequency of failure with higher fuel sulfur levels is believed to be due to the further suppression of NO_2 formation when higher sulfur level diesel fuel is used. Since this loss in regeneration effectiveness is due to sulfur poisoning of the catalyst this real world experience would be expected to apply equally well to nonroad engines (i.e., operation on lower sulfur diesel fuel, 15 ppm versus 50 ppm, will increase regeneration robustness).

As shown above, sulfur in diesel fuel inhibits NO oxidation leading to increased exhaust backpressure and reduced fuel economy. Therefore, we believe that, in order to ensure reliable and economical operation over a wide range of expected operating conditions, nonroad diesel fuel sulfur levels should be at or below 15 ppm.

4.1.7.1.2 Loss of PM Control Effectiveness

In addition to inhibiting the oxidation of NO to NO_2, the sulfur dioxide (SO_2) in the exhaust stream is itself oxidized to sulfur trioxide (SO_3) at very high conversion efficiencies by the precious metals in the catalyzed particulate filters. The SO_3 serves as a precursor to the formation of hydrated sulfuric acid (H_2SO_4+H_2O), or sulfate PM, as the exhaust leaves the vehicle tailpipe. Virtually all of the SO_3 is converted to sulfate under dilute exhaust conditions in the atmosphere as well in the dilution tunnel used in heavy-duty engine testing. Since virtually all sulfur present in diesel fuel is converted to SO_2, the precursor to SO_3, as part of the combustion process, the total sulfate PM is directly proportional to the amount of sulfur present in diesel fuel. Therefore, even though diesel particulate filters are very effective at trapping the carbon and the SOF portions of the total PM, the overall PM reduction efficiency of catalyzed diesel particulate filters drops off rapidly with increasing sulfur levels due to the formation of sulfate PM downstream of the CDPF.

SO_2 oxidation is promoted across a catalyst in a manner very similar to the oxidation of NO, except it is converted at higher rates, with peak conversion rates in excess of 50 percent. The SO_2 oxidation rate for a platinum based oxidation catalyst typical of the type which might be used in

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[Q] The average temperature in Helsinki, Finland, for the month of January is 21˚F. The average temperature in Stockholm, Sweden, for the month of January is 26˚F. The average temperature at the University of Michigan in Ann Arbor, Michigan, for the month of January is 24˚F. The temperatures reported here are from www.worldclimate.com based upon the Global Historical Climatology Network (GHCN) produced jointly by the National Climatic Data Center and Carbon Dioxide Information Analysis Center at Oak Ridge National Laboratory (ORNL).

conjunction with, or as a washcoat on, a CDPF can vary significantly with exhaust temperature. At the low temperatures the oxidation rate is relatively low, perhaps no higher than ten percent. However at the higher temperatures that might be more typical of agricultural tractor use pulling a plow and the on-highway Supplemental Emission Test (also called the EURO 4 or 13 mode test), the oxidation rate may increase to 50 percent or more. These high levels of sulfate make across the catalyst are in contrast to the very low SO_2 oxidation rate typical of diesel exhaust (typically less than 2 percent). This variation in expected diesel exhaust temperatures means that there will be a corresponding range of sulfate production expected across a CDPF.

The US Department of Energy in cooperation with industry conducted a study entitled DECSE to provide insight into the relationship between advanced emission control technologies and diesel fuel sulfur levels. Interim report number four of this program gives the total particulate matter emissions from a heavy-duty diesel engine operated with a diesel particulate filter on several different fuel sulfur levels. A straight line fit through this data is presented in Table 4.1-19 below showing the expected total direct PM emissions from a diesel engine on the supplemental emission test cycle.[R] The SET test cycle, a 13 mode steady-state cycle, that this data was developed on is similar to the C1 eight mode steady-state nonroad test cycle. Both cycles include operation at full and intermediate load points at approximately rated speed conditions and torque peak speed conditions. As a result, the sulfate make rate for the C1 cycle and the SET cycle would be expected to be similar. The data can be used to estimate the PM emissions from diesel engines operated on fuels with average fuel sulfur levels in this range.

Table 4.1-19
Estimated PM Emissions from a Diesel Engine at the Indicated Fuel Sulfur Levels

	Steady State Emissions Performance	
Fuel Sulfur [ppm]	Tailpipe PM[b] [g/bhp-hr]	PM Increase Relative to 3 ppm Sulfur
3	0.003	--
7[a]	0.006	100%
15[a]	0.009	200%
30	0.017	470%
150	0.071	2300%

[a] The PM emissions at these sulfur levels are based on a straight-line fit to the DECSE data; PM emissions at other sulfur levels are actual DECSE data. (Diesel Emission Control Sulfur Effects (DECSE) Program - Phase II Interim Data Report No. 4, Diesel Particulate Filters-Final Report, January 2000. Table C1.) Although DECSE tested diesel particulate filters at these fuel sulfur levels, they do not conclude that the technology is feasible at all levels, but they do note that testing at 150 ppm is a moot point as the emission levels exceed the engine's baseline emission level.
[b] Total exhaust PM (soot, SOF, sulfate).

Table 4.1-19 makes it clear that there are significant PM emission reductions possible with the application of catalyzed diesel particulate filters and low sulfur diesel fuel. At the observed sulfate PM conversion rates, the DECSE program results show that the 0.01 g/bhp-hr total PM standard is

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[R] Note that direct emissions are those pollutants emitted directly from the engine or from the tailpipe depending on the context in which the term is used, and indirect emissions are those pollutants formed in the atmosphere through chemical reactions between direct emissions and other atmospheric constituents.

feasible for CDPF equipped engines operated on fuel with a sulfur level at or below 15 ppm. The results also show that diesel particulate filter control effectiveness is rapidly degraded at higher diesel fuel sulfur levels due to the high sulfate PM make observed with this technology. It is clear that PM reduction efficiencies are limited by sulfur in diesel fuel and that, in order to realize the PM emissions benefits sought in this rule, diesel fuel sulfur levels must be at or below 15 ppm.

4.1.7.1.3 Increased Maintenance Cost for Diesel Particulate Filters Due to Sulfur

In addition to the direct performance and durability concerns caused by sulfur in diesel fuel, it is also known that sulfur can lead to increased maintenance costs, shortened maintenance intervals, and poorer fuel economy for CDPFs. CDPFs are highly effective at capturing the inorganic ash produced from metallic additives in engine oil. This ash is accumulated in the filter and is not removed through oxidation, unlike the trapped soot PM. Periodically the ash must be removed by mechanical cleaning of the filter with compressed air or water. This maintenance step is anticipated to occur on intervals of well over 1,500 hours (depending on engine size). However, sulfur in diesel fuel increases this ash accumulation rate through the formation of metallic sulfates in the filter, which increases both the size and mass of the trapped ash. By increasing the ash accumulation rate, the sulfur shortens the time interval between the required maintenance of the filter and negatively impacts fuel economy.

4.1.7.2 Diesel NOx Catalysts and the Need for Low Sulfur Fuel

NOx adsorbers are damaged by sulfur in diesel fuel because the adsorption function itself is poisoned by the presence of sulfur. The resulting need to remove the stored sulfur (desulfate) leads to a need for extended high temperature operation which can deteriorate the NOx adsorber. These limitations due to sulfur in the fuel affect the overall performance and feasibility of the NOx adsorber technology.

4.1.7.2.1 Sulfur Poisoning (Sulfate Storage) on NOx Adsorbers

The NOx adsorber technology relies on the ability of the catalyst to store NOx as a metallic nitrate (MNO_3) on the surface of the catalyst, or adsorber (storage) bed, during lean operation. Because of the similarities in chemical properties of SOx and NOx, the SO_2 present in the exhaust is also stored by the catalyst surface as a sulfate (MSO_4). The sulfate compound that is formed is significantly more stable than the nitrate compound and is not released and reduced during the NOx release and reduction step (NOx regeneration step). Since the NOx adsorber is essentially 100 percent effective at capturing SO_2 in the adsorber bed, the sulfur build up on the adsorber bed occurs rapidly. As a result, sulfate compounds quickly occupy all of the NOx storage sites on the catalyst thereby rendering the catalyst ineffective for NOx storage and subsequent NOx reduction (poisoning the catalyst).

The stored sulfur compounds can be removed by exposing the catalyst to hot (over 650˚C) and rich (air-fuel ratio below the stoichiometric ratio of 14.5 to 1) conditions for a brief period.[140] Under these conditions, the stored sulfate is released and reduced in the catalyst.[141] While research to date on this procedure has been very favorable with regards to sulfur removal from the catalyst, it has revealed a related vulnerability of the NOx adsorber catalyst. Under the high temperatures used for desulfation, the metals that make up the storage bed can change in physical structure. This leads to lower precious metal dispersion, or “metal sintering,” (a less even distribution of the catalyst sites) reducing the effectiveness of the catalyst.[142] This degradation of catalyst efficiency due to high temperatures is often referred to as thermal degradation. Thermal degradation is known to be a cumulative effect. That is, with each excursion to high temperature operation, some additional degradation of the catalyst occurs.

One of the best ways to limit thermal degradation is by limiting the accumulated number of desulfation events over the life of the engine. Since the period of time between desulfation events is expected to be determined by the amount of sulfur accumulated on the catalyst (the higher the sulfur accumulation rate, the shorter the period between desulfation events) the desulfation frequency is expected to be proportional to the fuel sulfur level. In other words for each doubling in the average fuel sulfur level, the frequency and accumulated number of desulfation events are expected to double. We concluded in the HD2007 rulemaking, that this thermal degradation would be unacceptable high for fuel sulfur levels greater than 15 ppm. Some commenters to the HD2007 rule suggested that the NOx adsorber technology could meet the HD2007 NOx standard using diesel fuel with a 30 ppm average sulfur level. This would imply that the NOx adsorber could tolerate as much as a four fold increase in desulfation frequency (when compared to an expected seven to 10 ppm average) without any increase in thermal degradation. That conclusion was inconsistent with our understanding of the technology at the time of the HD2007 rulemaking and remains inconsistent with our understanding of progress made by industry since that time. Diesel fuel sulfur levels must be at or below 15 ppm in order to limit the number and frequency of desulfation events. Limiting the number and frequency of desulfation events will limit thermal degradation and, thus, enable the NOx adsorber technology to meet the NOx standard.

This conclusion remains true for the on-highway NOx adsorber catalyst technology that this proposal is based upon and will be equally true for nonroad engines applying the NOx adsorber technology to comply with our proposed Tier 4 standards.

Nonroad and on-highway diesel engines are similarly durable and thus over their lifetimes consume a similar amount of diesel fuel. This means that both nonroad and on-highway diesel engines will have the same exposure to sulfur in diesel fuel and thus will require the same number of desulfation cycles over their lifetimes. This is true independent of the test cycle or in-use operation of the nonroad engine.

Sulfur in diesel fuel for NOx adsorber equipped engines will also have an adverse effect on fuel economy. The desulfation event requires controlled operation under hot and net fuel rich exhaust conditions. These conditions, which are not part of a normal diesel engine operating cycle, can be created through the addition of excess fuel to the exhaust. This addition of excess fuel causes an increase in fuel consumption.

Future improvements in the NOx adsorber technology, as we have observed in our ongoing diesel progress reviews, are expected and needed in order to meet the NOx emission standards proposed today. Some of these improvements are likely to include improvements in the means and ease of removing stored sulfur from the catalyst bed. However because the stored sulfate species are inherently more stable than the stored nitrate compounds (from stored NOx emissions) and so will always be stored preferentially to NOx on the adsorber storage sites, we expect that a separate release and reduction cycle (desulfation cycle) will always be needed in order to remove the stored sulfur. Therefore, we believe that fuel with a sulfur level at or below 15 ppm sulfur will be necessary in order to control thermal degradation of the NOx adsorber catalyst and to limit the fuel economy impact of sulfur in diesel fuel.

4.1.7.2.2 Sulfate Particulate Production and Sulfur Impacts on Effectiveness of NOx Control Technologies

The NOx adsorber technology relies on a platinum based oxidation function in order to ensure high NOx control efficiencies. As discussed more fully in Section 4.F.1, platinum based oxidation catalysts form sulfate PM from sulfur in the exhaust gases significantly increasing PM emissions when sulfur is present in the exhaust stream. The NOx adsorber technology relies on the oxidation function to convert NO to NO_2 over the catalyst bed. For the NOx adsorber this is a fundamental step prior to the storage of NO_2 in the catalyst bed as a nitrate. Without this oxidation function the catalyst will only trap that small portion of NOx emissions from a diesel engine which is NO_2. This would reduce the NOx adsorber effectiveness for NOx reduction from in excess of 90 percent to something well below 20 percent. The NOx adsorber relies on platinum to provide this oxidation function due to the need for high NO oxidation rates under the relatively cool exhaust temperatures typical of diesel engines. Because of this fundamental need for a precious metal catalytic oxidation function, the NOx adsorber inherently forms sulfate PM when sulfur is present in diesel fuel, since sulfur in fuel invariably leads to sulfur in the exhaust stream.

The Compact-SCR technology, like the NOx adsorber technology, uses an oxidation catalyst to promote the oxidation of NO to NO_2 at the low temperatures typical of much of diesel engine operation. By converting a portion of the NOx emissions to NO_2 upstream of the ammonia SCR reduction catalyst, the overall NOx reductions are improved significantly at low temperatures. Without this oxidation function, low temperature SCR NOx effectiveness is dramatically reduced making compliance with the NOx standard impossible. Therefore, future Compact-SCR systems would need to rely on a platinum oxidation catalyst in order to provide the required NOx emission control. This use of an oxidation catalyst in order to enable good NOx control means that Compact SCR systems will produce significant amounts of sulfate PM when operated on anything but the lowest fuel sulfur levels due to the oxidation of SO_2 to sulfate PM promoted by the oxidation catalyst.

Without the oxidation catalyst promoted conversion of NO to NO_2, neither of these NOx control technologies can meet the proposed NOx standard. Therefore, each of these technologies will require low sulfur diesel fuel to control the sulfate PM emissions inherent in the use of highly active oxidation catalysts. The NOx adsorber technology may be able to limit its impact on sulfate PM emissions by releasing stored sulfur as SO_2 under rich operating conditions. The Compact-SCR technology, on the other hand, has no means to limit sulfate emissions other than through lower catalytic function or lowering sulfur in diesel fuel. The degree to which the NOx emission control technologies increase the production of sulfate PM through oxidation of SO_2 to SO_3 varies somewhat from technology to technology, but it is expected to be similar in magnitude and environmental impact to that for the PM control technologies discussed previously, since both the NOx and the PM control catalysts rely on precious metals to achieve the required NO to NO_2 oxidation reaction.

At fuel sulfur levels below 15 ppm this sulfate PM concern is greatly diminished. Without this low sulfur fuel, the NOx control technologies are expected to create PM emissions well in excess of the PM standard regardless of the engine-out PM levels. Thus, we believe that diesel fuel sulfur levels will need to be at or below 15 ppm in order to apply the NOx control technology.

4.2. Supplemental Transient Emission Testing

4.2.1. Background and Justification

In the 1998 Rulemaking for Nonroad Compression Ignition Engines, we acknowledged that effective in-use control of emissions from nonroad sources would be positively impacted by having a duty cycle that more accurately characterized the transient nature of nonroad activity. While no certification cycle may guarantee complete in-use emissions control, a cycle that appropriately characterizes the activity of the subject equipment would afford a greater level of control. The basics of any nonroad transient duty cycle should include fulfillment of the following goals:

- represents nonroad activity broadly, with a basis in real world activities through diverse data segments;
- exercises the engine over its operating range. Cycle would not be limited to a specific speed or load, but traverses the operating range over the engine's full power range;
- measures particulate matter (PM) on a transient basis;
- captures the basic characteristics of PM, as currently defined, including:
    - organic and inorganic carbon fractions;
    - volatile fraction;
    - sulfate fraction;
    - ash, etc.
- ensures that control measures developed to control emissions over the cycle encourage and afford greater assurance that adequate control measures in-use

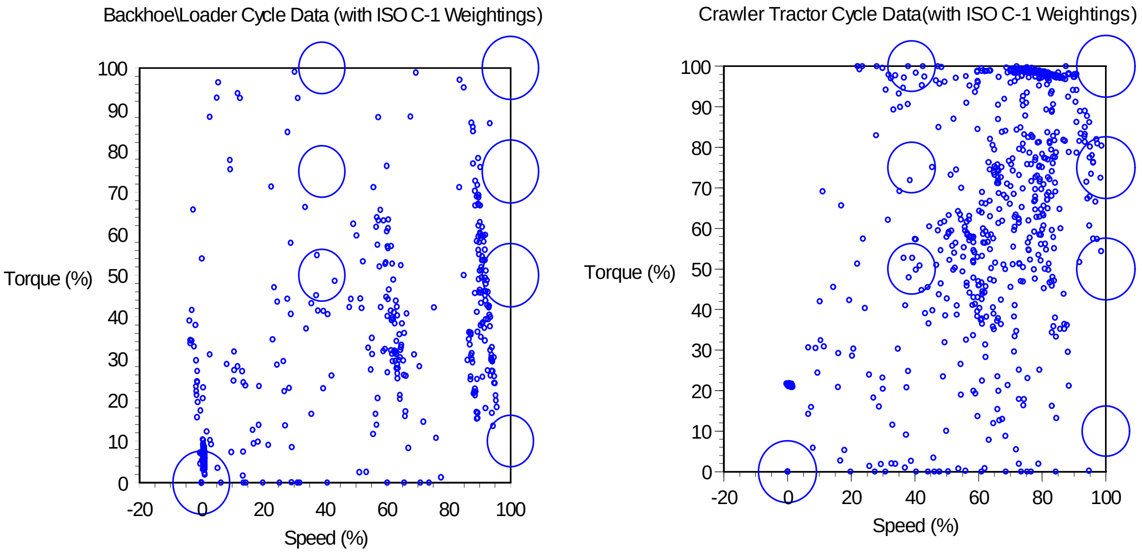
Since that rulemaking, we have embarked on a strategy for cataloging operational data, generating a duty cycle from those data sets, and compiling a transient composite duty cycle which provides a representation of a broad range of nonroad diesel equipment activity. Working cooperatively with the Engine Manufacturers Association (EMA), and through contract with the Southwest Research Institute (SwRI), we created a set of duty cycles based on the following nonroad applications:

- Agricultural Tractor
- Backhoe Loader
- Crawler Tractor
- Arc Welder
- Skid Steer Loader
- Wheel Loader
- Excavator

These application duty cycles were created from actual speed and load data recorded in-use on each of these pieces of equipment. The strategy for generating the duty cycles and the base data sets differed slightly. However, the combining of these two strategies has ensured that the strengths of both approaches would be integrated into the resultant composite duty cycle. Each of the pieces of equipment represented the top tier of nonroad equipment as defined by their contribution to nonroad diesel inventory as defined by the 1991 Nonroad Engine and Vehicles Emissions Study (NEVES). The pieces of equipment selected have retained their historical significance event today as they appear to match fairly well with EPA modeling data for the impacts of those applications.

The existing steady state duty cycle affords good coverage of the range of activity seen by nonroad diesel applications, however it is incomplete. The range of nonroad activity is much broader and much more varied than can be captured by a set of steady state points. Please see Figure 4.2-1. It should be clear that no single transient cycle, of reasonable length, could capture the full body of nonroad diesel activity in the real world. It is possible to capture typical operation of nonroad equipment and to extrapolate the applicability of available data to the remainder of nonroad equipment for purposes of certification and modeling. This could not replace an in-use characterization, however it does drive development of engine control strategies to focus emissions and performance parameters on a broader set of activity that is much more likely to be seen in-use.

Figure 4.2-1
Backhoe Loader and Crawler Tractor Cycle Data versus the ISO 8178-4 C1 Cycle



Backhoe\Loader Cycle Data (with ISO C-1 Weightings)

Crawler Tractor Cycle Data(with ISO C-1 Weightings)

A much broader set of data from the nonroad duty cycle generation may be found in Memorandum from Cleophas Jackson to the EPA Air Docket A-2001-28. This operational and cycle data demonstrate the amount of nonroad activity that can occur outside the modes of the ISO C1 duty cycle.

4.2.1.1 Microtrip-Based Duty Cycles

The microtrip-based cycles were created based on a range of activity the equipment would likely see in use. The weighting of each microtrip impacted the duration of each segment within the resulting duty cycle. Each microtrip was extracted from a full set of data with the equipment being operated within the targeted implement application. The data from the extracted segment was compared to the full body of data for the targeted implement application based on a chi square analysis, with a 95% confidence level, of the nature of the operation. This included a characterization of the speeds, loads, velocities, and accelerations over the full operating map, for the given piece of equipment. Experienced operators conducting actual work operated each unit. The projects ranged from an actual farmer plowing to a backhoe digging a trench for a municipal works project to a wheel loader in a rock quarry loading a truck to a skid steer loader preparing plots in a subdivision under construction. The microtrip-based application duty cycles were the Agricultural Tractor cycle, the Backhoe Loader cycle and the Crawler/Dozer cycle.

4.2.1.2 "Day in the Life"-Based Duty Cycles

In attempting to address real world activity another strategy was employed for the second set of nonroad duty cycles. This approach was termed the "day in the life" strategy. It could be said that this approach yielded only a single or perhaps two microtrips per piece of equipment. This approach was employed to capture data for work that would have otherwise have been done regardless of EPA data collection needs. With these pieces, the data recorded was simply data generated as selected pieces of equipment were used by contractors or construction personnel during their normal operation versus being asked to do certain types of operation. The “day in the life”-based application duty cycles consisted of the Skidsteer Loader cycle, the Arc Welder cycle, the Rubber Tire Loader cycle, and the Excavator cycle. The Excavator Cycle is in fact a composite duty cycle assembled from three equal time segments of operating data from two different excavators.

4.2.2. Data Collection and Cycle Generation

4.2.2.1. Test Site Descriptions

Operators were instructed to complete a job commensurate with the functionality of the vehicle and at their customary pace. Experienced operators conducted their normal work with a given piece of nonroad equipment. The work conducted by the equipment was actual work and not artificial scenarios, so that the data accuracy was ensured.

4.2.2.1.1. Agricultural Tractor Cycle Operation

The John Deere agricultural tractor was operated by an experienced farmer on his farm. The farmer was asked to conduct the following activities as if he normally would on any given work day. This activity formed the basis for the microtrips for the agricultural tractor duty cycle. The microtrip activity segments included: planter, tandem offset discing (35 foot), bedder, cultivator, ripper (10 row), folding chisel plow, and turnaround. The work was conducted during spring planting season in Hamlin, Texas, using an actual in-use field being prepared for cultivation. The tractor was used to make passes with each selected implement. The normal load operation retained for inclusion in the cycle generation was the “normal” operation with each implement. The data from the intentionally, highly loaded pass was not included in the eventual Agricultural Tractor cycle.

4.2.2.1.2. Backhoe Loader Cycle Operation

The Caterpillar backhoe loader was utilized on a site by the City of Houston, Utility Maintenance Division, Fleet Management Department to conduct the following activities: roading, trenching, loading and grade and level. The operation was conducted by a municipal employee experienced in the operation of the backhoe conducting that activity. Engine data was collected during the repair of a collapsed city sewage line in a residential neighborhood. The activity included demolishing the road over the sewage line, trenching to reach the pipe, craning to remove the old pipe and install the new pipe, backfilling, loading, spreading gravel, and finish- grading the site.

4.2.2.1.3. Crawler Tractor Cycle Operation

The Caterpillar D4 Tractor was used to conduct the following activity on the grounds of Southwest Research Institute by an experienced operator. The microtrips included road bed preparation, clearing activity, and pit activity. The operation was examined at three independent sites. Site 1 included clearing trees and brush for a construction site. At Site 2 the equipment dug and prepared a road bed. At Site 3 V-trench and pit operations were examined. This activity was similar to preparing a site for a small building foundation.

4.2.2.1.4 Wheel Loader Operation

The Caterpillar 988F Wheel Loader was operated at Redland Stone Products Company (quarry) in San Antonio, Texas. Data was collected between June 8 and June 10, 1998. The equipment was operated from morning until midnight, working to fill construction and mining trucks, open-topped trailers of Class-8 highway trucks, and rail cars[143]. The material being moved was typical quarry material which included aggregate of various material densities such as crushed stone, gravel, and sand. Twenty-six hours of data was gathered at the quarry for the wheel loader.

4.2.2.1.5 Skid Steer Loader Operation

The Daewoo skid steer loader was operated at a construction site for a new complex of townhouses in the San Antonio, Texas, area by a commercial site preparation company. The equipment was used to create drives for individual homes. Specifically, the skid steer loader was used to haul and position aggregate foundation material to prepare the driveway and sidewalk areas prior to laying asphalt. Over twelve hours of data was gathered over three work days for the skid steer loader. The implement used by the skid steer loader during this operation was its bucket.

4.2.2.1.6 Arc Welder Operation

The Lincoln Electric 250-amp arc welder was operated at Redland Stone Products Company (quarry) in San Antonio, Texas. Data was collected over a single work day. The equipment was used to perform repairs on a large, mobile steel crusher tower by a private contract firm, Holt. Eight hours of data was gathered at the quarry for the arc welder.

4.2.2.1.7 Excavator Operations

The Hitachi EX300LC excavator was operated at 3 different sites over 7 days in the greater San Antonio metropolitan area. Data was collected during Winter 1998 and Spring 1999. The equipment was used to level ground at a building site, to load aggregate materials into trucks at a quarry and to dig trenches and transport pipes for a sewer project. Almost thirty-nine hours of data was gathered for this excavator.

The Caterpillar 320BL excavator was operated at 4 different sites over 6 days in the greater San Antonio metropolitan area. Data was collected during Winter 1998 and Spring 1999. The equipment was used to perform digging, trenching, pipe transport and placement and backfilling associated with an on-going sewer project. More than thirty-eight hours of data was gathered for this excavator.

4.2.2.2 Engine and Equipment Description

In generating the microtrip-based and the day-in-the-life-based duty cycles, the equipment selected were based on the highest sales volume applications and the contribution of those applications to the ambient inventories for NOx and PM. Those cycles were created based on a John Deere 4960 Agricultural Tractor, Caterpillar 446B Backhoe Loader, and a Caterpillar D4H Crawler Tractor. The detailed description of the engines[144] may be seen in Table 4.2-1 through Table 4.2-3.

Table 4.2-1
Agricultural Tractor—John Deere 4960

Engine Characteristic	Value
Rated Speed (rpm)	2200
Peak Torque (Nm)	970
Peak Power (kW)	189.2
Low Idle Speed (rpm)	850
Operating Range (rpm)	850-2400
Other Engine Descriptors	7.6L displacement, electronic controls

Table 4.2-2
Backhoe Loader—Caterpillar 446B

Engine Characteristic	Value
Rated Speed (rpm)	2200
Peak Torque (Nm)	405
Peak Power (kW)	76.8
Low Idle Speed (rpm)	800
Operating Range (rpm)	800-2300
Other Engine Descriptors	CAT 3114-D17 engine

Table 4.2-3
Crawler Tractor—Caterpillar D4H

Engine Characteristic	Value
Rated Speed (rpm)	2200
Peak Torque (Nm)	442
Peak Power (kW)	85
Low Idle Speed (rpm)	800
Other Engine Descriptors	3204-D17 engine

The engines that were used for data generation for the “day in the life” -based approach were based on a skid steer loader, an arc welder, and a wheel loader. The engine parameters of the Caterpillar 988F Series II rubber tire loader, the Lincoln arc welder and the Daewoo skidsteer loader are listed in Table 4.2-4 through Table 4.2-6.

Table 4.2-4
Rubber Tired Loader—1997 Caterpillar 988F Series II

Engine Characteristic	Value
Rated Speed (rpm)	2080
Peak Torque (Nm)	2908
Peak Power (kW)	321
Low Idle Speed (rpm)	850
Operating Range (rpm)	850-2250
Other Engine Descriptors	CAT 3408E-TA engine, Caterpillar HEUI Fuel System, electronic

Table 4.2-5
Arc Welder—1997 Lincoln Electric Shield-Arc 250

Engine Characteristic	Value
Rated Speed (rpm)	1,725
Peak Torque (Nm)	162
Peak Power (kW)	28.3
Low Idle Speed (rpm)	1375
Operating Range (rpm)	800-1900
Other Engine Descriptors	Perkins D3.152 engine

Table 4.2-6
Skid Steer Loader—1997 Daewoo DSL-601

Engine Characteristic	Value
Rated Speed (rpm)	2,800
Peak Torque (Nm)	121 Nm
Peak Power (kW)	30.6 kW
Low Idle Speed (rpm)	800
Peak Torque Speed (rpm)	1,700
Other Engine Descriptors	Yanmar 4TNE84 engine, 2.0 L Displacement, in-line 4 cyl, naturally aspirated

Two pieces of equipment were selected for generating the excavator duty cycle based on estimates of equipment population and horsepower distribution among excavators in the U.S. nonroad equipment inventory at that time[145]. With the highest excavator sales volumes being in the 60-130 kW and 130-225 kW ranges, the Agency created its excavator duty cycle based on both a Hitachi EX300LC excavator at 155 kilowatts (208 horsepower) and a Mitsubishi/CAT 320 BL excavator at

95 kilowatts (128 horsepower). The detailed description of the engines may be seen in Table 4.2-7 and Table 4.2-8.

Table 4.2-7
Excavator (higher power output)—1997 Hitachi EX300LC

Engine Characteristic	Value
Rated Speed (rpm)	2,200
Peak Torque (Nm)	Nm (636 lbs-ft)
Peak Power (kW)	155 kW
Low Idle Speed (rpm)	680
Peak Torque Speed (rpm)	1,500
Other Engine Descriptors	ISUZU A-6SD1TQA(AC/JI) engine, 9.8 L displacement, mechanical controls

Table 4.2-8
Excavator (lower power output)—1997 Mitsubishi/CAT 320 BL

Engine Characteristic	Value
Rated Speed (rpm)	1,800
Peak Torque (Nm)	Nm (473lbs-ft)
Peak Power (kW)	95 kW
Low Idle Speed (rpm)	800
Peak Torque Speed (rpm)	1,200
Other Engine Descriptors	Mitsubishi/CAT 3066T engine, 6.4 L displacement

4.2.2.3 Data Collection Process

The data collection process for both the microtrip-based and the day in the life duty cycles was based on collecting engine operational data in the field by mechanical and electronic means. Engine speed data were measured by instrumenting the engine of each piece of equipment with a tachometer to measure engine speed in revolutions per minute (rpm). The torque was measured either mechanically by linear transducer or as transmitted across the engine's control area network as a fuel-based torque signal. The mechanical torque measurement utilized rack position to determine the load being demanded of the engine. To calibrate the voltage signal from the linear actuator the engine rack position versus actual fuel rate and engine-out torque were determined based on laboratory evaluation of the same model engine. Once a map of engine speed, load, actual torque, and fuel rate was compiled, the in-field load could be determined based on rack position and engine speed as measured by the tachometer.

Data loggers were used to record field data during operation and the data loggers were equipped with flash memory media. The data loggers only recorded engine on operation, therefore data was not gathered while the engine was stopped. Data collection rates varied from cycle to cycle from a rate of 3.33 Hz to 5 Hz. Using cubic spline interpolation, the data was then reduced to 1 Hz format for the purpose of cycle generation.

4.2.2.4 Cycle Creation Process

The basic methodology of comparing extracted segments to the full body of data was used for both duty cycle types. The major difference is in how the activity was defined for each. The microtrip-based activity specified the type of work performed by various implements for a given piece of nonroad equipment in an effort to effectively incorporate the different types of operation through which the equipment could be exercised over its lifetime. The day in the life approach was meant simply to characterize the nature of the full range of activity seen by the equipment during its typical operation over the period of evaluation. The body of data for neither approach was meant to be all encompassing to the extent that no other activity would be expected from that piece of equipment over its lifetime. The microtrip approach represents the broadest sweep in the compilation of nonroad operation. The resulting duty cycles in each case do represent the most representative set of data from the full body of data collected.

4.2.2.4.1 Microtrip Cycle Creation

The contractor that conducted the in field testing and data reduction was Southwest Research Institute (SwRI) with significant input from the Engine Manufacturers Association (EMA) and direction from the United States Environmental Protection Agency (EPA). The methodology used for creating the microtrip-based cycles involved extracting the actual data by comparing the running window of actual data to the full body of data that was collected for each type of activity. This involved a chi-square[S] analysis comparing observed to expected data. The observed data set was the data being evaluated for inclusion in the cycle for the specific active window. The expected data set was represented by the full body of data from the given activity. The chi-square comparison involved assessing the following for each window of operation:

- Rate of change in speed (dSpeed)
- Rate of change in torque (dTorque)
- Power
- Rate of change in power (dPower)
- Speed and torque
- Torque and dSpeed
- Speed and dTorque
- Duration and magnitude of change in power

The specific steps involved in cycle generation were the following:

1. Separate the raw vehicle data into data files by vehicle activity.

[S] $\sum(O_i - E_i)^2 / E_i$ where O_i is the Observed frequency in the ith interal and E_i is the Expected frequency in the ith interval based on the frequency distribution of the entire population for the given quantity.

2. Load first activity file.
3. Calculate power. Add to raw data file.
4. Normalize speed using FTP process and manufacturer's specified rated speed. Normalize torque, and power using measured peak values and create a scalar-normalized data file.
5. Calculate the time derivative of normalized speed, torque, and power.
6. Calculate the duration and magnitude of all increases, decreases, and steady-state periods from the normalized power data.[T] Count occurrences of duration and magnitude of changes in power for selected ranges.
7. Count occurrences of power and rates of change of speed, torque, and power for selected ranges. Count occurrences of speed and torque, change in speed at selected torque levels, change in torque at selected speed levels, and duration and magnitude of changes in power for selected ranges. The relative frequencies of occurrence (RFO) were collected within the specified ranges of activity (e.g. normalized range of speed of 20 units).
8. Characteristic graphs of each activity was created for each piece of equipment. Several formats were used to characterize the various analysis of the equipment operation:
    - Scatter plots of normalized speed and load data
    - RFO data for delta[U] speed versus normalized torque
    - RFO data for normalized speed versus delta normalized torque
    - RFO plots of magnitudes and duration of delta power
9. The analysis of steps 1-8 was conducted by SwRI for each activity for each duty cycle.
10. The scalar normalized speed data (based on manufacturer specified rated speed) and normalized torque (or load - based on the peak torque available at the given speed) was used to generate the final set of activity comparisons for extracting the "actual" data for the microtrip from the full body of activity data collected for the specific application.

Microtrip Weightings

The microtrips of the agricultural tractor cycle, backhoe loader cycle, and crawler cycle were weighted based on feedback from the engine manufacturers on the amount of time each application was expected to operate using a given implement performing a set function over the lifetime of that piece of equipment. The microtrip weighting for the Agricultural Tractor cycle may be seen in Figure 4.2-2 to Figure 4.2-4. The cycle creation was based on linking the microtrips with transition points between each activity segment.

[T] Steady State is defined as any instantaneous change in normalized speed or normalized torque with a magnitude less than 2%.

[U] Delta is used to describe the instantaneous rate of change of the specified quantity.

Figure 4.2-2

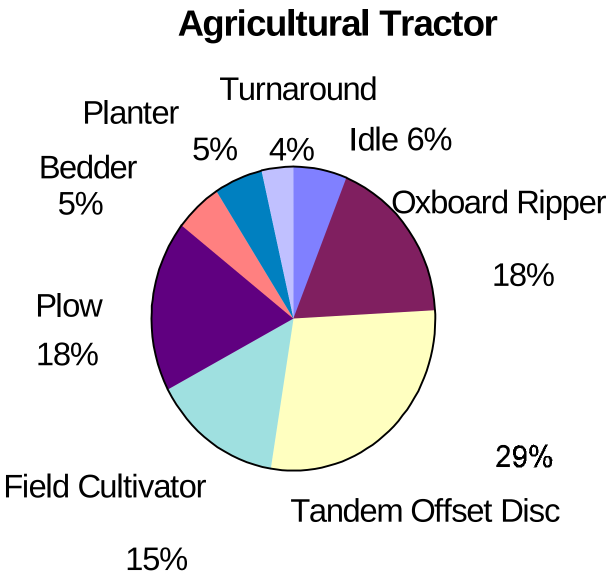


Figure 4.2-3

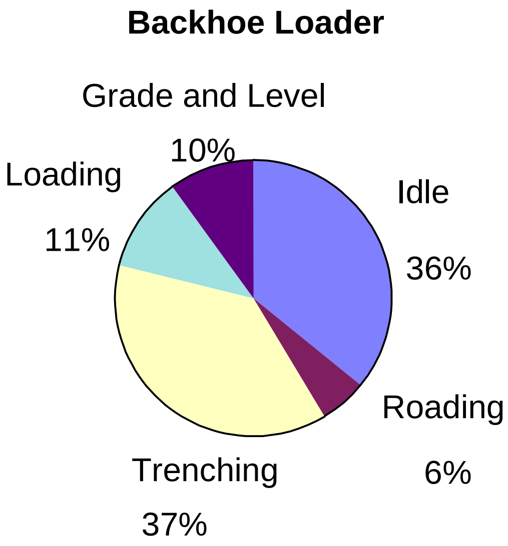
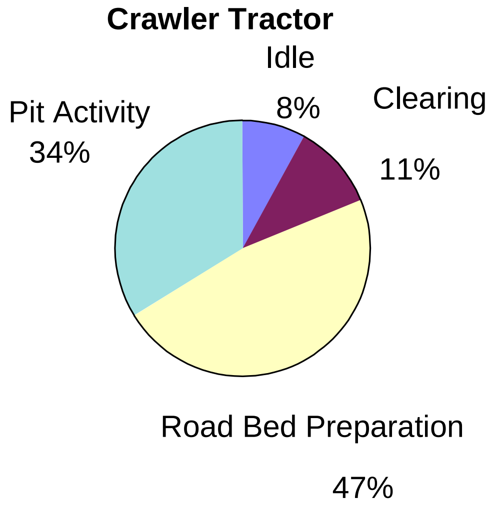


Figure 4.2-4



In generating the duty cycles and conducting the analyses, relative frequency of occurrence of various parameters as reported by the contractor were compared to the full set of real world data. Figure 4.2-5 shows the difference in the full set of real world data collected versus the microtrip, for one activity type. As can be seen in this figure, the difference in the total data set and the identified microtrip was relatively small, based on the relative frequency of occurrence.

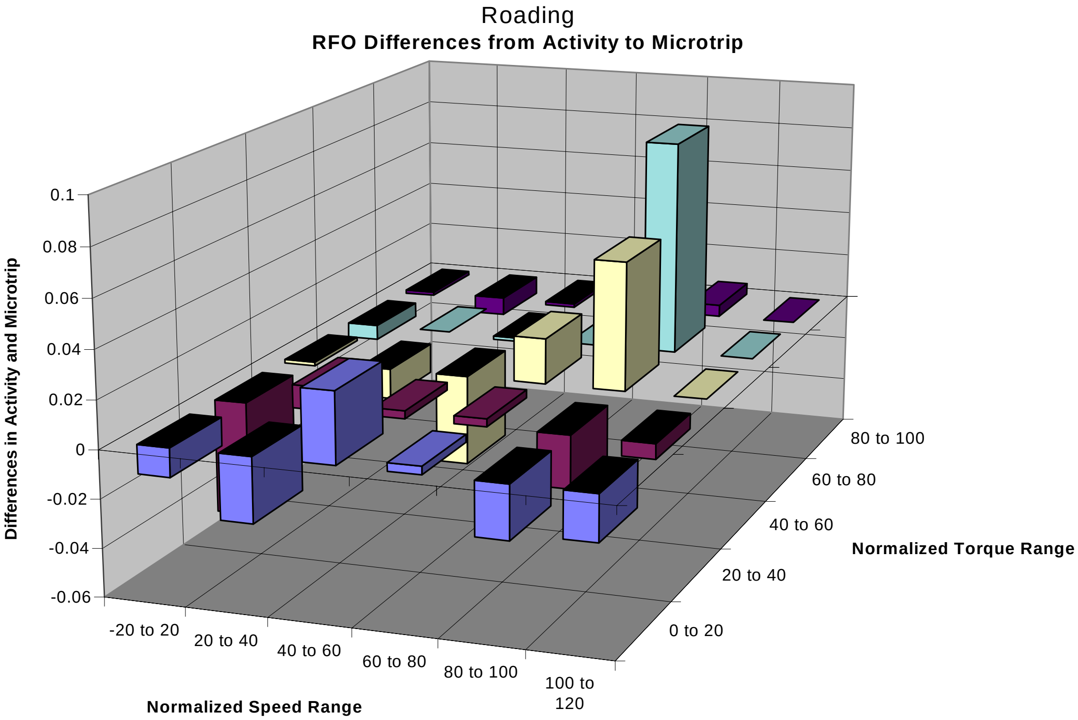


Figure 4.2-.5
Example of Microtrip vs. Data Set for Tractor Activity

Cycle Creation

Each of the microtrip-based duty cycles were created based on the statistical analysis previously described. The linked component microtrips were then reduced to 1 Hz data from the original 3.33 Hz signal using a cubic spline interpolation. The duty cycle was then speed and torque normalized, based on the maximum available power/torque mapping. These duty cycles were the first set of cycles that would be used for creation of the nonroad transient composite duty cycle.

4.2.2.4.2 “Day in the Life” Cycle Generation

In generating the day in the life data, a similar chi-square analysis was used to compare RFO data from the running window of data versus the full body of data. The distinction lies in that this was not done for multiple activity types for each piece of equipment. The analysis was conducted using a nineteen-minute window incremented at one-minute intervals. The approach used for data reduction, while similar, also varied in that the bin increments used for the day in the life duty cycles was 100 rpm and 200 lb-ft for torque versus the normalized 20 percent windows from the microtrip approach. The steps taken by SwRI are as follows.

1. Define “bins” sized at 100 rpm for speed by 200 ft-lb for torque.

2. Sort entire data file (e.g. 376,768 observations ~ 26 hours) into bins.
3. Compute a frequency table to indicate the number of observations contained in each bin. Similar to the RFO bins from the microtrip analysis.
4. Increment within data file by 1 minute, and sort the next 19 minutes
5. Compute the chi-square statistic for comparison with frequency distribution of the population data file.
6. The approach to analyzing each nineteen-minute “window” of activity was repeated at one-minute increments for the entire body of data.
7. The window of activity that best represented the full body of data for that piece of equipment was selected as the most typical duty cycle.
8. Four iterations on the analysis was conducted to develop a typical 1 duty cycle, a typical 2 duty cycle, a high transient speed[V] duty cycle, and a high transient torque duty cycle for each application.
9. For each window of activity, the data used was the actual, contiguous data from the body of data for that piece of equipment.

Given the nature of this data generation process, the detailed analysis needed for weighting the microtrips and determining the time basis for inclusion into a composite cycle was not needed. The resulting duty cycles were simply the result of the extraction of data from the complete raw data set, which were subsequently normalized.

4.2.2.4.3. Excavator Cycle Generation

Data files for each piece of equipment were appended together in chronological order to form a data population for that excavator. Each data population contained columns for time of data acquisition (incremented at 5 Hz), engine speed, and rack position. Data for engine speed and rack position were used to compute a column for torque in units of pound-feet (lb-ft), based on the rack-to-torque algorithm using correlation information compiled earlier for the corresponding excavator engine. Tasks of choosing the representative segments to form a composite excavator cycle were then initiated based on these two different data populations.

The in-use data population of each excavator was sorted into two-dimensional intervals or “bins,” and a histogram was compiled based on the frequency of occurrences for speed and torque pairs within the designated bins. The percent or relative frequency of occurrence (RFO) is considered a histogram that describes the data population. Therefore, by choosing a segment that closely matched the characteristic RFO compilation, it is rationalized that the chosen segment is indeed representative of the given data population. Using the same bin intervals as were applied to create a histogram (RFO) for each data population, a similar histogram was created for each 380-second candidate segment of data. Each candidate segment overlapped the previous segment by 320 seconds, as the process for excerpting candidate segments incremented through the data population using a 60-second step size. Chi-square analyses tested each candidate segment to rank each segment by comparing its RFO histogram to the RFO histogram created for its associated data population. The following is the approach used for computing a chi-square statistic, relative frequency of occurrence distributions to that of the corresponding population for engine speed and torque values, for each candidate segment:

[V] High transient duty cycles (speed or torque) represent the single most transient speed or torque window of data (highest number and magnitude of instantaneous changes in speed or torque) from the full body of data.

1. Define “bins” for speed expressed in rpm, and torque as lb-ft
2. Sort each data population (approximately 38 hours, at 5 Hz) into bins
3. Compute a relative frequency of occurrence table to indicate the percentage of observations contained in each bin
4. Increment through the data population by 60 seconds, sort the next 380-second segment into similar bins, and compute a relative frequency of occurrence table
5. Compute a chi-squarea statistic for comparing the frequency distribution of the segment to that of the population
6. Repeat Steps 4 and 5 for all such 380-second candidate segments, for an entire data population
7. Sort segments by increasing chi-square rank (low statistic means good correlation)

Note: The chi-square statistic is the summation of:

$$(O_i - E_i)^2 / E_i$$

where O_i is the observed frequency in the ith interval of the 380-second sample window, and E_i is the expected frequency of the ith interval based on the frequency distribution of the entire population.

The sliding 380-second "window" was used to determine the distribution of speed-torque combinations experienced by each type of equipment over the entire range of operating data collected on each unit. The "window" was advanced by one-minute increments through the data to determine a most typical segment for each excavator and a second most typical segment for the lower-powered unit.

Based on initial torque map information obtained with each engine on the steady-state test bench, a normalizing process was applied to each of the 5 Hz data segments (part of “data smoothing”). FTP normalizing methods outlined in the 40 CFR part 86, subpart N, were used for expressing observed engine speed and torque values for the three selected segments of 5 Hz data in terms of the percentage of an engine’s full load performance and idle speed. The 5 Hz data for segments chosen to represent the first- and second-most typical segments in the data population generated with the Caterpillar 320BL excavator were normalized using the rated speed and torque map information obtained with the Caterpillar 3066T engine mounted on the steady-state test bench. Similarly, the 5 Hz data for the segment best representing the typical operation of the higher powered Hitachi excavator was normalized using torque map information obtained for the Isuzu A-6SD1T engine on the steady-state test bench.

An averaging method was applied to the three selected segments to convert each segment from the original 5 Hz to 1 Hz data files. Each 5 Hz data pair was first normalized and then the percentage values were averaged. In general, the smoothing technique produced a value for speed and a value for torque for each one-second interval (1 Hz) by averaging the five values in the interval of interest.

After establishing in-use operating engine speed and torque data populations for excavators rated in both the low and high power ranges, three representative segments were appended together to form a 20-minute composite excavator cycle. The first two segments were the most representative data from the lower and higher powered excavators, respectively. The third segment represented the second-most typical data from the lower-powered excavator (i.e., ranked number two in chi-square analyses for that population). This resulted in a composite cycle which was apportioned with two thirds data gathered from the Caterpillar 320BL excavator rated in the 100 to 175 hp range, and one third from data gathered from the Hitachi EX300LC excavator rated in the 176 to 300 hp range. The three segments were then joined into a composite 20-minute excavator duty cycle by the addition of appropriate transition segments leading into and linking each segment of transient operation. A three-second transition joined Segment 1 and Segment 2, and similarly another three-second transition joined Segments 2 and 3. A no-load idle condition was appended for 27 seconds at the beginning and end of the cycle.

4.2.3 Composite Cycle Construction

Having all seven application cycles in hand, including the four cycle variations apiece for the arc welder, skidsteer loader and rubber-tire loader, we began construction of a transient composite nonroad duty cycle. The approach for addressing the weighting of contributions from each equipment type to the composite cycle was left at equally weighting each contribution. While consideration was given to population weighted or inventory based weighting factors for the composite cycle, in the interest of ensuring a universally applicable cycle, no unique weighting factors were assigned. The decision of which data segments to extract from the component duty cycles was based on uniqueness of operation (avoidance of replicate data in the composite cycle) and level of transient operation (steady state operation[W] was not included in the transient cycle). Extracted cycle segments were linked using three second transition periods, when needed, to ensure smooth transitions within the cycle and to avoid spurious data generation based on changes in speed and load that were unrealistic between segments. Transition periods were deemed necessary when the change in the magnitude of the torque or speed value was greater than twenty using the normalized data. The cycle was constructed using the denormalized segments for each component cycle based on the original engine map for the engines used to generate the component cycles. Once the raw data was available, the normalization based on the max speed map was conducted. This was necessary because each cycle was originally normalized using different procedures (e.g. FTP speed and torque normalization or GCS[X] speed with FTP torque normalization). The MAP used for normalizing the raw data remained FTP-based (percent of maximum torque at the given speed) for torque. The Maximum Speed Determination was used for the speed normalization. Figure 4.2-6 identifies the location of the cycle segments as extracted from the component application duty cycles, the segment duration, and segment position in the composite duty cycle.

[W] Steady State Operation is defined as an instantaneous speed or torque change less than 2% of the maximum magnitude.

[X] GCS Speed or Governed Central Speed is defined as the speed corresponding to the point along the engine's MAP (maximum allowable power) curve at which power is 50% of maximum measured rated power once the maximum measured power has been surpassed.

Figure 4.2-6

Supplemental NRTC (Nonroad Transient Composite) Cycle

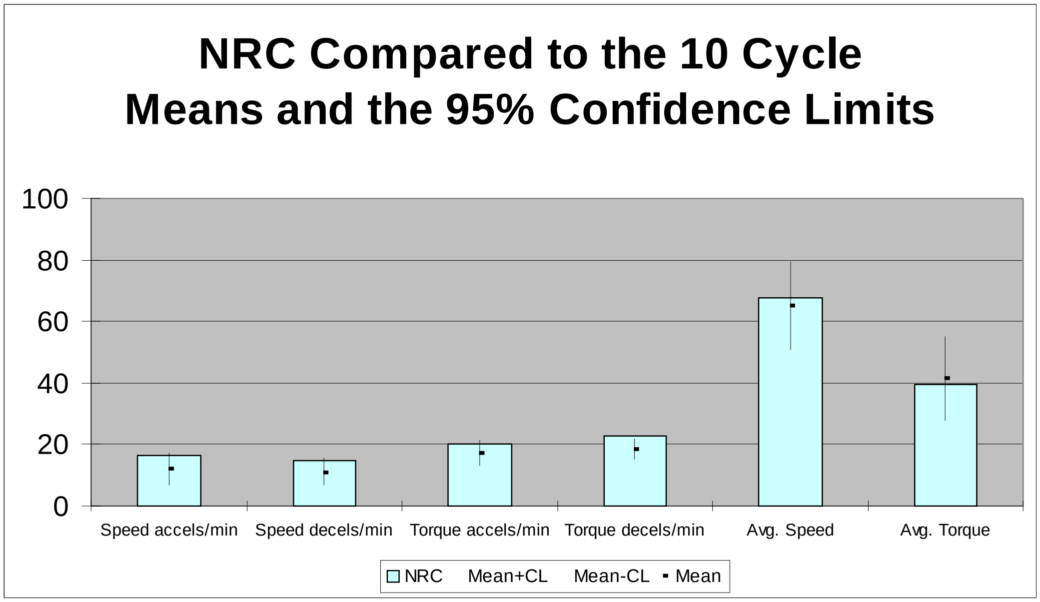
Application Number	Nonroad Application	Application Duration (seconds)	Application in Cycle Position (#seconds)	Segments from Application Cycle (#seconds)	Segment Name	Segment Duration (seconds)	Cumulative Cycle Time (seconds)	Segment in Cycle Position (#seconds)
					Start/Transition	28	28	0-28
1	Backhoe Loader	206	29-234	52-86	Roading	35	63	29-63
				108-141	Trenching	34	97	64-97
				174-218	Loading	45	142	98-142
				351-442	Grade/Level	92	234	143-234
2	Rubber-Tire Loader	184	235-418	746-822	Typical Operation	77	311	235-311
				531-637	Hi-Spd Transient	107	418	312-418
3	Crawler-Dozer	209	419-627	85-206	Road Bed Prep	122	540	419-540
				376-462	Clearing	87	627	540-627
4	Agricultural Tractor	150	628-777	265-414	AgTractor	150	777	628-777
5	Excavator	35	778-812	319-338	LowerHp (128Hp)	20	797	778-797
				431-445	HigherHp (208Hp)	15	812	798-812
					Transition	3	815	813-815
6	Arc Welder	204	816-1019	1007-1103	Typical Operation	97	912	816-912
				544-650	Hi-Spd Transient	107	1019	913-1019
7	Skid Steer Loader	185	1020-1204	264-365	Typical Operation	102	1121	1020-1121
				150-232	Hi-Trq Transient	83	1204	1122-1204
					Idle/Transition/End	34	1238	1215-1238

4.2.4 Cycle Characterization Statistics

The characterization of the operational data was also subsequently revisited for purposes of comparison in addressing composite cycle construction. The nature of the transient activity is characterized in a report to EPA by Dyntel.[146] The goal of the analysis was to provide an assessment of the transient nature of nonroad activity between different applications. These analyses (small bin, large bin, and general cycle) were used to address the comparability of the resulting composite nonroad diesel transient duty cycle to the component data set that was collected for each of the component cycles. The size of the bin was simply a reference to the scale used for the analysis (either coarse or fine). As may be seen in Figure 4.2-7, the composite nonroad transient duty cycle fit well within the average of all of the original nonroad duty cycles based on the operational data. The figure is a plot of the nonroad composite cycle characteristics with the statistics of the remainder of the nonroad diesel cycles plotted as a mean with the standard deviation between those statistics from the other cycles shown. The ten cycles represented include:

- Ag Tractor
- Crawler
- Skid Steer Typical 1
- Wheel Loader High Torque Transient
- Arc Welder High Torque Transient
- Backhoe
- Arc Welder Typical 2
- Wheel Loader Typical 1
- Excavator
- Skid Steer Loader High Torque Transient

Figure 4.2-7
Summary of Nonroad Cycles Comparison to NR Composite



4.2.5 Cycle Normalization / Denormalization Procedure

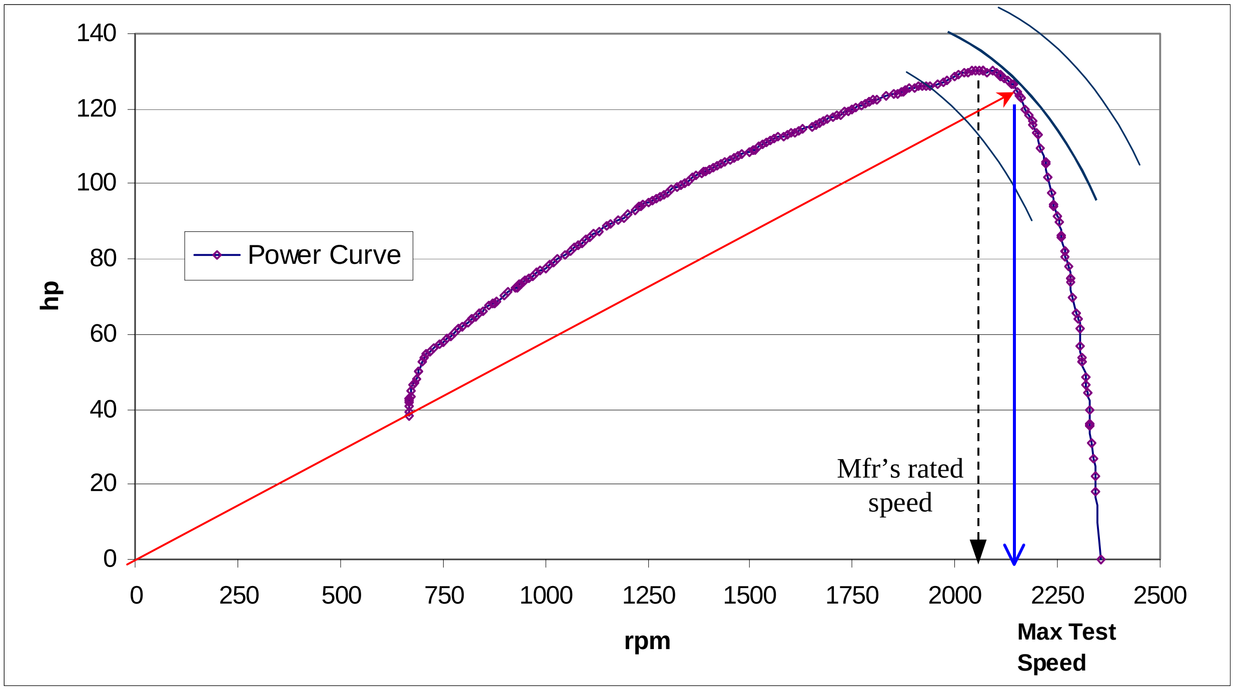
The actual values for speed and load in rpm and lbs-ft for each of the application cycles needed to be converted to normalized values before any application cycle could be used on an engine other than the engine originally used to create the application cycle itself. This process of normalization entailed converting the actual in-use operating speed and load values of the "raw" duty cycle, as recorded from the engine used to create the cycle originally, into a percentage of that engine's maximum achievable speed and load values. This yields a duty cycle schedule of speed and load values which, because the schedule points are in percent of an engine's maximum measured rpm (speed) and lbs-ft (load), the cycle can be converted over to the true speed and load values, in rpm and lbs-ft, required to run that cycle on any other engine, if one has the new engine's maximum achievable power (MAP) validation. Multiplying the percentage values of the normalized cycle by the measured speed and load maximums of the new engine's MAP curve, in fact, denormalizes the cycle. This means that the denormalized speed and load values may be used as commanded values on a test cell dynamometer to exercise the new engine in exactly the same manner as the original engine was run for a particular application cycle. The load values in lbs-ft for each of the seven types of application cycles and all their cycle permutations, i,e., Typical, High Transient Speed , etc., were all converted to normalized values (and conversely, into denormalized values, at later times) using the FTP normalization procedure detailed in 40 CFR Part 86. The speed values in rpm for each type of application cycle were normalized initially in one of three different ways.

The speed values in each of the original microtrip cycles, the agricultural tractor, backhoe loader, and crawler-dozer, were all normalized using the FTP procedure. The speed values in each of the original "day in the life" cycles, rubber tire loader, skidsteer loader and arc welder were all normalized using the governed central speed procedure (GCS)[Y]. The speed values in the excavator cycle were normalized, and later denormalized, using the FTP normalization procedure detailed in 40 CFR Part 86. However, in time and for the construction of EPA's composite nonroad cycle, all the application cycles were normalized using the Agency's Maximum Speed determination procedure.

The Maximum Speed Determination procedure uses the measured speed and load values from an engine's power curve to determine what is the maximum power that the engine can attain and at what speed that engine will achieve its maximum power. This value for speed at maximum power can then be used in lieu of a manufacturer's rated speed number for a particular engine to conduct a normalization or denormalization of engine or cycle for purposes of running a duty cycle on a particular engine. The procedure is based on a speadsheet calculation [147] and is discussed in a report entitled "Summary and Analysis of Comments: Control of Emissions from Marine Diesel Engines", document # EPA420-R-99-028 in Chapter 8, "Test Procedures"[148]. As detailed in Figure 4.2-8 below, the maximum speed can be found below the point on the engine power curve that is the farthest distance from the point of origin of the graph of engine's measured speed and power values. That farthest point on the curve is described as the point of maximum power achievable by the engine under study.

[Y] GCS is the speed value on the Maximum Achievable Power (MAP) curve of an engine at which the engine's speed is 50% of the measured rated power for that engine, after measured rated power has been passed on the MAP curve.

Figure 4.2-8
Maximum Test Speed Determination



4.2.6 Cycle Performance Regression Statistics

In assessing the nonroad transient duty cycles, ten nonroad diesel engines were exercised over the nonregulatory[149] nonroad duty cycles to assess emissions impacts of each duty cycle, as well as to determine the ability of typical nonroad diesel engines to pass the existing highway cycle performance regression statistics. That data may be seen in a report from SwRI with an accompanying EPA summary of the results in the Memorandum to the EPA Air Docket 2001-28 from Cleophas Jackson entitled *Nonroad Duty Cycle Regression Statistics.* Subsequent analysis on the composite nonroad transient cycle was based on test cell data collected from testing at the National Vehicle and Fuel Emissions Laboratory and Southwest Research Institute, as well as through the European Commission's Joint Research Center (EC-JRC), and various engine manufacturers from the United States, Europe, and Japan.

4.2.7 Constant-Speed Variable-Load Transient Test Procedure

Some nonnroad diesel engines are required by the equipment which they have been designed to power, and the equipment's specific application, to operate in a constant-speed manner. While the operating speed in many cases is not truly constant, it is generally true that the unit's speed will vary little during operation. This equipment is more tolerant of changes in operating load than other more closely governed constant-speed nonroad engines. Some pieces of constant-speed equipment will be governed to a nominal "zero" variation in rpm during operation for critical operations such as maintenance of electrical power and refrigeration. For these engines which are designed to operate under restricted transient conditions, the Agency is proposing an alternative transient duty cycle over which a nonroad engine manufacturer may choose to operate their engine(s) to comply with EPA's new transient nonroad testing requirement. This cycle, the Constant-Speed Variable-Load (CSVL) application duty cycle, is derived from EPA's Arc Welder Highly Transient Torque application duty cycle. The cycle schedule, its commanded speed and load values, may be found at proposed regulations in 40 CFR Part 1039, Appendix “I”. A manufacturer certifying their equipment to this cycle would be constrained to allow their engines to operate equipment in-use only in a constant-speed, variable-load manner.

EPA recognizes that some constant speed equipment is designed to operate near or at its rated engine rpm during much or most of that equipment’s useful life. The Agency’s CSVL cycle, while designed for a broad range of constant speed nonroad engines, has an average speed which may be lower than the speed at which a manufacturer has designed their engine to operate at maximum efficiency. While the CSVL cycle would still test that engine in a manner which might be encountered by these types of engines under real world operation, EPA has given the nonroad engine manufacturer who believes that their engine to be certified will be sensitive to the speed fluctuations found in the CSVL cycle the option, within the transient test regulations, to operate their engine at a set speed, determined by the operating specifications of the engine, for the course of the CSVL cycle. This variation is described in proposed regulations at 40 CFR Part 1048, section 510. Set speed operation will allow the manufacturer to run the CSVL cycle at the rated speed of the equipment to be certified for the entire length of the cycle or to specify some constant percent of rated speed at which to operate the equipment or engine to be certified. The load portion of the CSVL duty schedule would remain unchanged under this modification. As in the previous case, a manufacturer certifying their equipment on this cycle would be constrained to specify this restricted set speed, variable load manner of operation in-use for their engines.

4.2.7.1 Background on Cycles Considered

As has been described earlier in Part 4 of the Draft RIA, the Arc Welder application cycles were developed on an arc welder/electric generator, running a constant speed application at a variable load, with a direct-injection, naturally-aspirated, 30kW (40 hp) engine. The Arc Welder Highly Transient Torque cycle, one of the four cycles developed on this engine, is based on a single twenty-minute segment of all the real time operating data collected on this engine.

Some manufacturers of constant-speed application engines have raised issues with EPA’s proposed CSVL cycle. One issue arises from manufacturers of high brake-mean effective pressure (BMEP), i.e., high rated power, constant-speed engines. They point out that the smaller BMEP engine on which the Arc Welder cycles were developed was more responsive to torque changes than their high BMEP engines were designed to encounter. As such, these manufacturers feel that their engines may be penalized by the number and magnitude of torque changes in the CSVL cycle. We do not believe that this concern will significantly affect emissions performance for Tier 4 engines because PM control is realized through mechanical filtration of the PM and as such is largely independent of operating conditions (see the PM emissions performance noted in tables 4.1-2 through 4.1-5). Similarly, NOx and NMHC control is expected to be realized with catalyst systems, that although temperature dependent, are expected to be fully functional over the range of operation for the CSVL cycle as evidenced by the steady-state emissions results shown in figure 4.1-11 (EPA modes 5,6,7,8 and 17,18,19,20). Further, manufacturers can improve catalyst performance at low torque operating modes by increasing the use of EGR to both lower engine-out NOx emissions while simultaneously raising exhaust temperatures to promote more effective catalyst function (see discussion in 4.1.3 above). Therefore, we can conclude with confidence that compliance with the proposed Tier 4 standards are feasible over the CSVL cycle.

A second issue involves the average load experienced by an engine running on the proposed CSVL cycle. The average load factor of the normalized application cycle is approximately 25% of engine capacity. Manufacturers of constant speed engines which have a significantly higher load factor on their engines during operation, closer to the 90% and greater range of normalized engine load at constant speed, have argued that their engines will not be able to pass cycle regression statistics for certification without significant re-tuning of the engines to operate over the CSVL cycle. EPA will follow developments with specific manufacturers where the CSVL cycle is anticipated to require substantial re-tuning, or even redesign, of engine controls in order to pass this cycle for engine compliance with transient testing requirements.

4.2.7.2 Justification of Selections

The CSVL cycle should assure manufacturers that their constant-speed engines are able to meet in-use emission and NTE standards. While the CSVL cycle may not be able to accommodate the particular operating parameters required to run every constant speed engine, it is a fairly robust cycle for many types of constant-speed equipment and applications. With a manufacturer's option to use a set operating speed over the course of the test cycle, even fewer concerns should arise as to operating an engine over this transient cycle. EPA has shown further that one can pass cycle regression statistics on a typical nonroad engine with fairly mild cycle control procedures in place[150]. The Agency feels that "tailoring" the constant speed cycle to multiple engines and applications will further fragment the certification process for constant-speed engine manufacturers and in the end, will afford less control over in-use engine emissions than maintaining the CSVL cycle alone as the single certification option for the class of constant-speed engines. Given future engine technology and trends in emission control, this cycle will represent a boundary for operating emissions from these engines. By certifying engines to this testing procedure, manufacturers can be assured that their engines will be as clean as, and may be even cleaner, operating in-use than operating over the CSVL cycle for certification.

Manufacturers may choose to run the CSVL cycle for certification purposes at a set speed instead of following the intended speed trace from the CSVL cycle, where their constant speed engine(s) is governed very closely during actual engine operation. EPA is proposing this set speed option to the CSVL cycle as a form of relief for these engines which normally are used to power applications like electricity-generating sets and some refrigeration units. Details of this option may be found at proposed regulations in 40 CFR Part 1068.

To pass cycle regression statistics for cycle performance on the CSVL cycle, an engine must have achieved the performance parameters for speed, load and power found in table 4.2-14. These values are the same regression statistics used to determine pass or fail on EPA's NRTC cycle and they do not impose any greater burden on constant-speed engine manufacturers who choose engine compliance with the CSVL transient test cycle than might be seen with operating their engines over the NRTC cycle for compliance.

The Arc Welder cycles were corrected in the course of developing EPA's composite nonroad duty cycle to accommodate for the fact that idle, as listed in early cycle versions, was actually an intermediate speed for the engine (due to its limited high-speed range during transient operation) and that the actual engine idle speed was closer to 800 rpm. As any idle point listed in the original cycles was also idle for the application and not for the engine, this change was seen as appropriate. Speed changes that were based on low idle to high rated excursions were changed to peak torque speed to rated excursions.

Contractor testing of EPA's Arc Welder cycles has yielded mixed results in passing regression statistics upon later analysis, but passing regression statistics on these cycles was not the principal goal of many of the individual cycle development and testing programs[151]. Many times, the contractor was only required to optimize the test engine to the case of running a transient FTP for passing statistics on the test engine[152] and, subsequently, many different application cycles were then run on the same engine in conjunction with the transient FTP cycle.

Most recently, though, EPA has run both its Arc Welder Typical 1 and Highly Transient Torque application cycles in-house on an electric dynamometer with a turbocharged 93 kW (124 hp) test bed engine[153]. The realtime control strategies employed on the dynamometer cycle runs included simple PID (proportional, integral, and derivative) control algorithm-derived time constants and a half second earlier time-shift of commanded throttle (torque) values in the denormalized cycle. These control measures correct for anticipated differences in feedback from the actual speed and torque values for the engine during operation and the command values from the dynamometer during testing. The commanded throttle (torque) values were time-shifted, again, in a post-analysis of cycle data in half-second increments. Out of 20 half-second values, cycle regression statistics were passed on all parameters, for speed, torque and power, for three consecutive time values for the Arc Welder Typical cycle and on six consecutive time shift values for the Arc Welder Torque cycle. This form of post-processing is fairly typical for duty cycle testing conducted in a dynamometer test cell and would not create a significant added burden on the manufacturer.

4.2.8 Cycle Harmonization

4.2.8.1 Technical Review

One concern raised by the engine manufacturers was that the mapping method used to generate the real world torque data introduced an error by no appropriately accounting for the impact of transient activity of the actual torque signal from the engine. The basis of the issue was primarily a torque signal in the field, based on the rack position, that may not have actually occurred had an in-line torque meter been employed. There are two aspects of this which warrant review. The first aspect of actual torque versus inferred torque. The second aspect of this issue is whether or not rack position or the demanded load is an appropriate metric for developing real world based duty cycles. To address the second issue in the context of responsiveness of a nonroad engine, it should be clear that although feedback torque from the engine provide a clear signal of what was accomplished by the engine, it is not a fair metric of the demanded load. Given the fact that a typical operator or driver would tend to demand a desired torque the engine's response to that demand, although not distinct, is a separate issue. It is this reasoning through which command cycles are generated. The command cycle represents the speed and load demanded of the engine, the engine's responsiveness could be addressed through the performance statistics.

Engine manufacturers sought to address the first concern through a playback analysis which addressed the Iα correction as an offset to the commanded load signal. The playback approach would involve rerunning one of the engines (identical engine model) in the test cell over the defined duty cycle with the calculated Iα offset to measure torque using an in-line torque meter. Manufacturers provided the inertia data for their engines either used for cycle development or anticipated to be included in the testing program. The data provided by members of the Engine Manufacturers Association (EMA) may be seen in Table 4.2-9 and Table 4.2-10.

Table 4.2-9
Nonroad Diesel Engines Used for Cycle Generation

No.	Engine Mfg	Engine Model	Machine Mfg	Machine Model	Application	Rated Power (Kw)	Peak Torque (N m)	Rated Speed (RPM)	Low Idle (RPM)
1	Caterpillar	3204-D17	Caterpillar	Cat D4H	Crawler Tractor	85 peak	442	2200	800
2	Caterpillar	3114-D17	Caterpillar	Cat 446B	Backhoe Loader	76.8 peak; 70.8 rated	405	2200	800
3	Caterpillar	3408E - TA	Caterpillar	988F-II	Wheel Loader (2)	321		2100	850
4	Isuzu	A-6SD1 TQA	Hitachi	EX-300LC	Excavator High Power	161	834	2000	850
5	John Deere	6081	John Deere	JD 4960	Ag Tractor	186	970	2200	850
6	Mitsubishi	3066T	Caterpillar	Cat 320 Excavator	Excavator Low Power	95	641	1800	860
7	Perkins	'97 D3.152	Lincoln	97 'Shield-Arc' 250, K1283	Arc Welder	28		1725	800 (1)
8	Yanmar	'97 4TNE84	Daewoo	DSL-601	Skid Steer Loader	31	121	2800	800

Table 4.2-10
Engine Inertia Data Used for Iα Correction Calculation

No.	Engine Mfg	Engine Model	Total Inertia (Kg-m2)	Total Inertia (N-m-s2)	Engine Inertia (N-m-s2 = kg-m2)	Flywheel Inertia (N-m/s2 = kg-m2)
1	Caterpillar	3204-D17	1.7899	1.7899	0.2249	1.5650
2	Caterpillar	3114-D17	0.9770	0.9770	0.5550	0.4220
3	Caterpillar	3408E - TA	2.8637	2.8637	1.3147	1.5490
4	Isuzu	A-6SD1 TQA	7.5303	7.5303	2.8263	4.7040
5	John Deere	6081	2.4400	2.4400	0.5000	1.9400
6	Mitsubishi	3066T	0.9160	0.9160	0.2160	0.7000
7	Perkins	'97 D3.152	0.1083	0.1083	0.1083	
8	Yanmar	'97 4TNE84	0.2317	2.3629		

The correction that was undertaken by EPA and Southwest Research Institute (SwRI) used the following methodology. The original 3 Hz data set was used to correct the torque data rather than interpolated 1 Hz data to ensure the raw data was corrected to avoid error propagation within the 1 Hz scalar data.

1. Apply the Iα correction to calculate the new torque command.
2. Apply original technique to create 1 Hz raw command cycles using the cubic spline interpolation for the those cycles that were originally collected at 3.33 Hz.
3. Each resultant correct raw data duty cycle was then normalized using the Maximum Speed determination method.[Z]
4. Cycle segments for the Composite Nonroad Transient duty cycle were then reassemble from the component duty cycles.

The result of the correction, as conducted by SwRI, was that there were very small modifications to the most severe torque excursions. The peaks and valleys were trimmed slightly. The overall change in the cycle resulted in less than 0.5% correction, typically.

[Z] Please see Draft RIA Section 4.2.3. of this rulemaking

4.2.8.2 Global Harmonization Strategy

4.2.8.2.1 The Need for Harmonization

Given the increasingly global marketplace in which nonroad engines are sold, alignment of standards and procedures helps facilitate introduction of cleaner technology at lower across in multiple markets. Given the nature of the nonroad diesel market with a large number of very diverse product offerings and in some cases, small niche market volumes, the ability to design once for different markets helps reduce the costs, especially of the lower volume equipment models. While alignment of limit values may be a key component of harmonized regulations, alignment of test procedures, measurement protocols, and other aspects of certification and testing procedures helps reduce the testing burden a given manufacturer would have to face when selling and distributing their product in multiple markets. Much of the development of new procedures and test methods has originated in the United States, Europe, and Japan. While other markets tend to adopt emissions limits and procedures as a part of a more global process on a different time frame. Given the nature of regulatory and technological development, allowing the leading markets for which new technology will need to be introduced to have comparable protocols simply reduces the costs those markets will be forced to absorb. In any effort to utilize procedures in multiple regulatory arena care should be taken to include an assessment of equivalence and appropriateness. In so doing, both Europe and the United States conducted an assessment of real world operation of nonroad diesel equipment. The data collection effort in the United States started in 1995. The subsequent data collection effort in Europe confirmed that, as expected, nonroad diesel activity in Europe was comparable.

In moving forward with a single test cycle for both Europe and the United States, and potentially a global nonroad diesel cycle, the basic framework for the cycle was agreed upon. In addition to the work initiated by the Agency in compiling a nonroad transient duty cycle, it was important to ensure that concerns about global suitability be addressed. The context used for this assessment in Europe was the existing European Transient Cycle (ETC). While this duty cycle was developed for heavy duty, highway diesel applications, it was seen as an adequate basis for which European industry and government staff could assess the proposed EPA Nonroad Transient Duty Cycle. Representatives from Japan’s government and industry have periodically participated in this process as well, however no such framework for comparison was requested for the evaluation process from any representative from Japan. Throughout the development of the duty cycle, industry representatives from the United States, Europe, and Japan have provided detailed technical input. In Table 4.2-11 shows early results presented by Deutz exercising a nonroad diesel engine over the EPA generated Nonroad Transient Duty Cycle indicating an ability to pass cycle performance criteria with only a slight problem with the Torque Intercept statistic.

Table 4.2-11
Initial Deutz Data Submission for EPA Nonroad Diesel Transient Duty Cycle (Nov. 13, 2000)

			Speed	Torque	Power
Standard error of estimate (SE)	measured	NRTC	56,48 rpm	7,58%	7,15%
		ETC	24,29 rpm	6,59%	5,67%
	tolerance		max 100 rpm	max 13%	max 8 %
Slope of the regression line (m)	measured	NRTC	1,010	0,925	0,968
		ETC	0,990	0,963	0,976
	tolerance		0,95 to 1,03	0,83 to 1,03	0,89 to 1,03
Regression coefficient (r^2)	measured	NRTC	0,996	0,958	0,973
		ETC	0,993	0,980	0,981
	tolerance		min 0,9700	min 0,88	min 0,91
Y intercept of the regression line (b)	measured	NRTC	18,01 rpm	30,10 Nm	3,62 kW
		ETC	17,67 rpm	5,80 Nm	0,62 kW
	tolerance		+/- 50 rpm	+/- 20 Nm	+/- 4 kW

red:	out of tolerance
green:	near to tolerance limit

4.2.8.2.2. Harmonization Methodology

The composite Nonroad Transient (NRTC) duty cycle developed by the Agency was used as the reference cycle for which subsequent development and testing work would be conducted. It was originally introduced to the global regulatory community and engine industry in Geneva in June 2000. After an on-going dialogue with industry in the United States and Europe, additional modifications were suggested by the European Commission based on manufacturer concerns with their ability to meet test cell performance statistics with this duty cycle. In September 2001, it was decided by a joint European, American, and Japanese government and industry workgroup that the then "candidate" cycle would be used by the Joint Research center to conduct additional changes commensurate with the goal of not allowing the instantaneous transient speed and torque changes to be greater than those experienced within the European Transient Cycle (ETC). Using a Bessel filtering algorithm, the cycle was then modified by the EC-JRC to meet the ETC target of 23% of torque events faster than 4 seconds. The two cycles may be seen on a time basis in Figures 4.2-9 and 4.2-10. The average load and average speed of each cycle are shown in Table 4.2.6.2.2.-1. The speed characteristics of the original cycle were similar to the speed characteristics of the ETC. This is not an indication that the speed trace was identical, but rather that the maximum instantaneous speed changes of the NRTC were similar to the maximum instantaneous speed changes of the ETC.[AA]

[AA] Memorandum to EPA Air Docket A-2001-28 from Cleophas Jackson, *Report from the JRC entitled Contribution to the NRTC Development Based on Test Data Supplied by Engine Manufacturers*, February 26, 2001

Figure 4.2-9
EPA Nonroad Transient Test Cycle as of March 2001

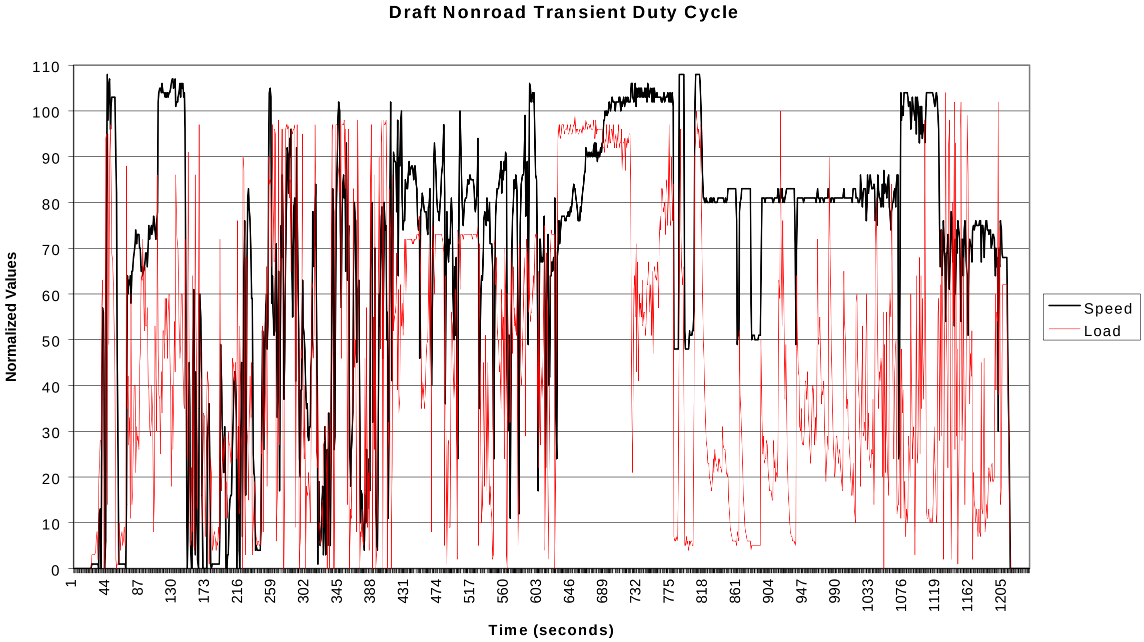


Figure 4.2-10
JRC Nonroad Transient Test Cycle after Bessel Filtering

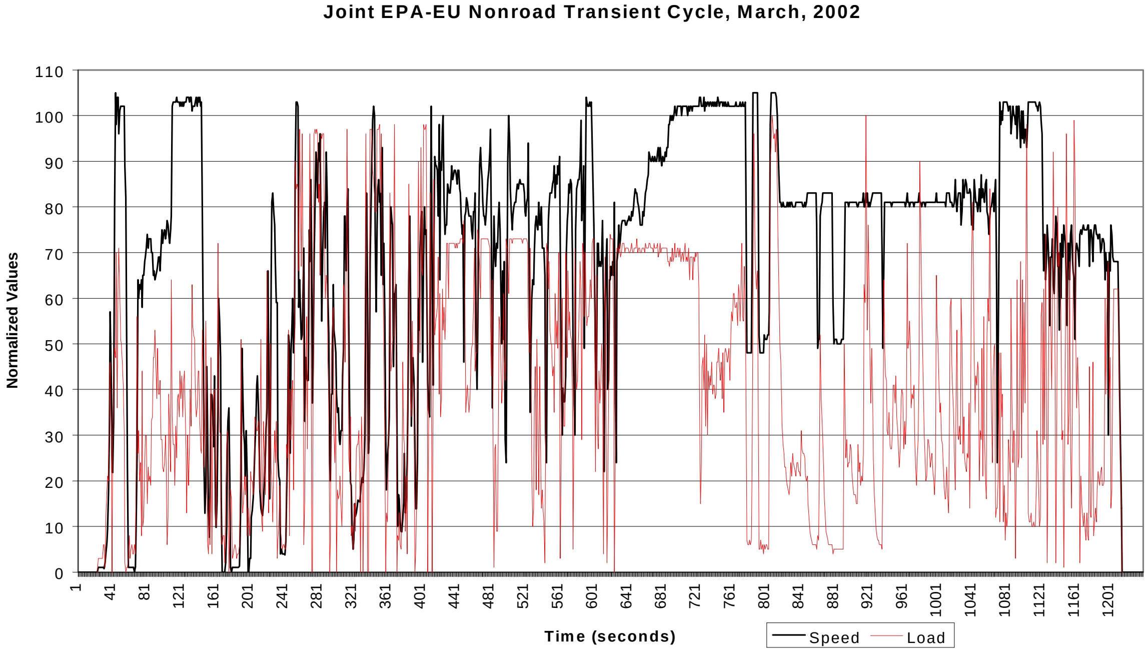


Table 4.2-12
Comparison of Cycle Averages

Duty Cycles	Average Normalized Speed	Average Normalized Torque
EPA NRTC	63%	47%
JRC Modified NRTC	68%	39%

The following figures describe the JRC Modified NRTC with respect to speed and load and the transient nature of the cycle. This will be contrasted with the same characteristics of the EPA generated NRTC. The JRC modified NRTC was also known as the San Antonio cycle or the JRC.

Figure 4.2-11

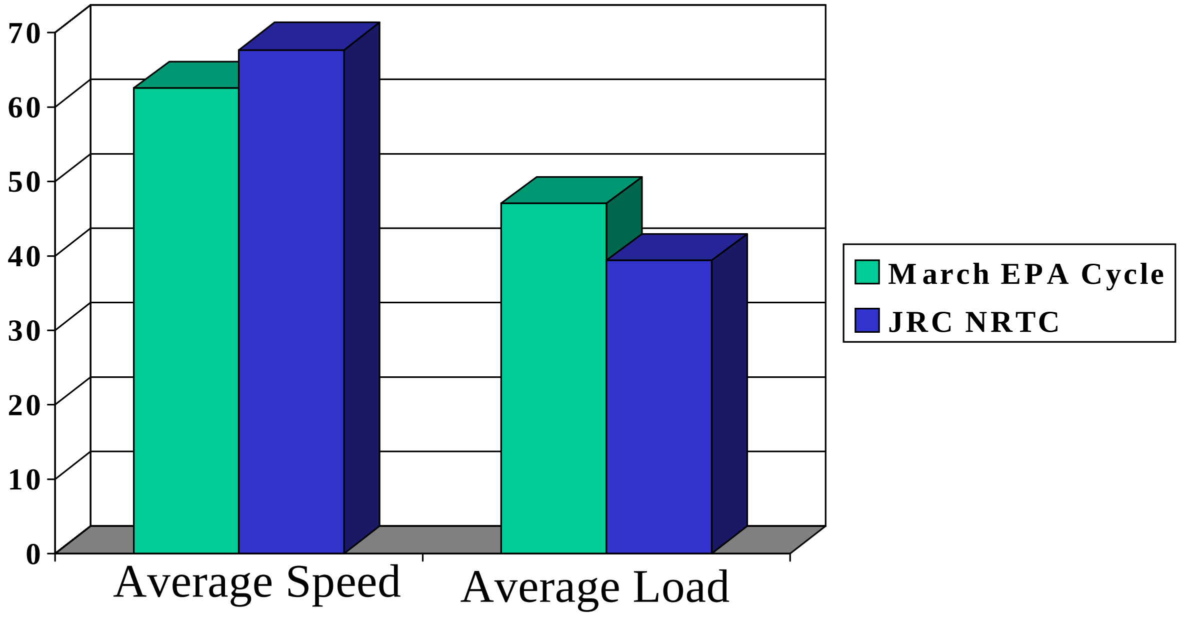


Figure 4.2-12
Average Speed Changes of the EPA NRTC

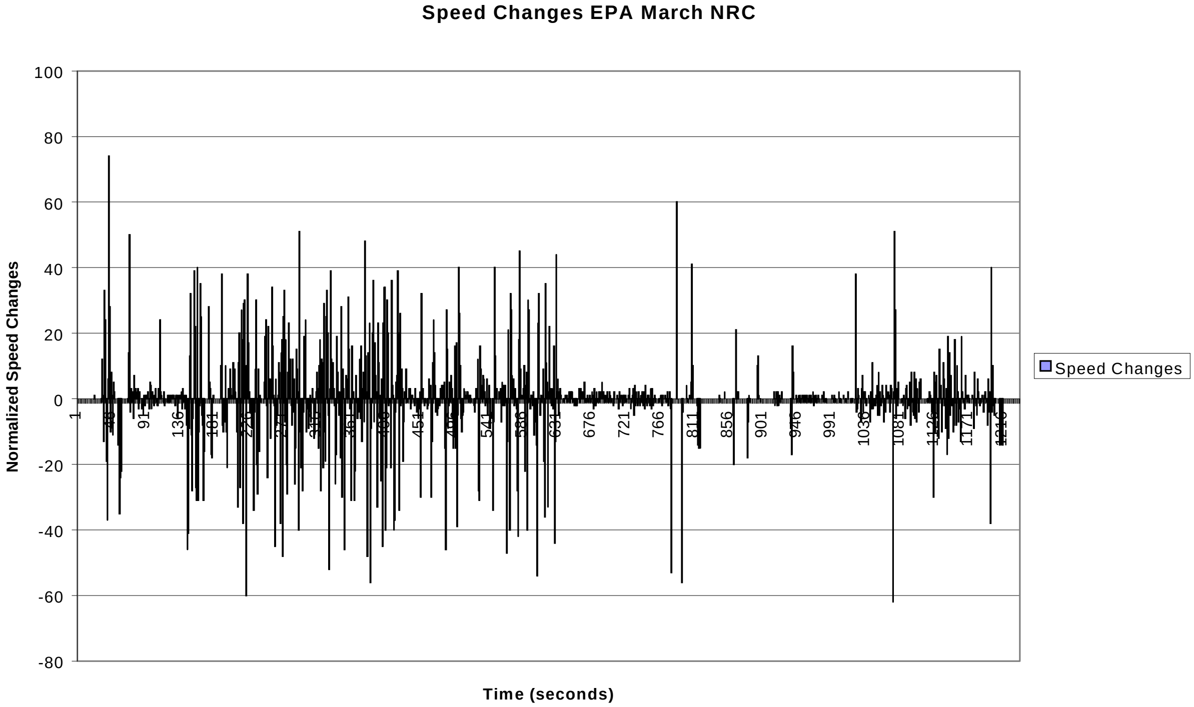


Figure 4.2-13
Average Speed Changes of JRC Modified NRTC

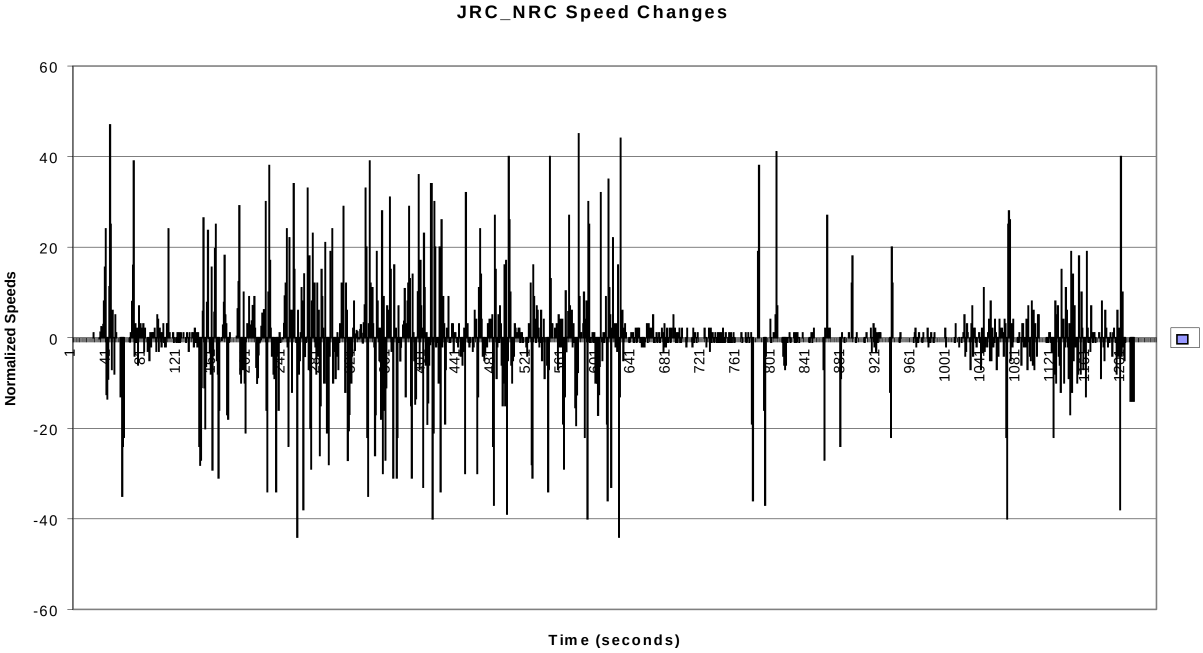


Figure 4.2-14
Average Load Changes of JRC Modified NRTC

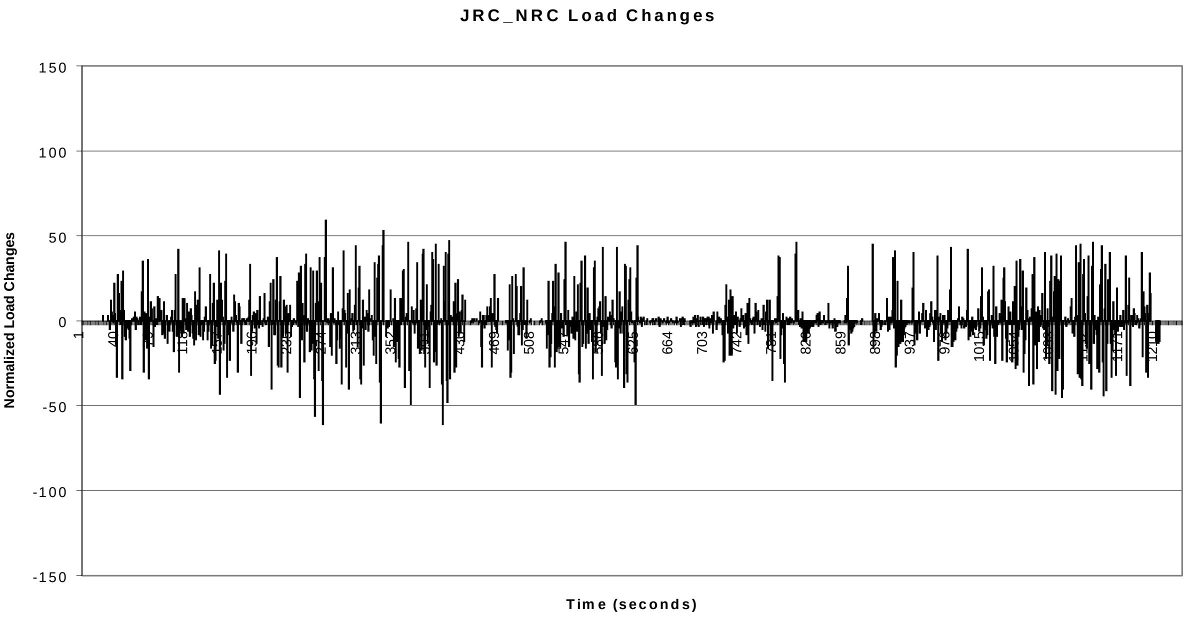
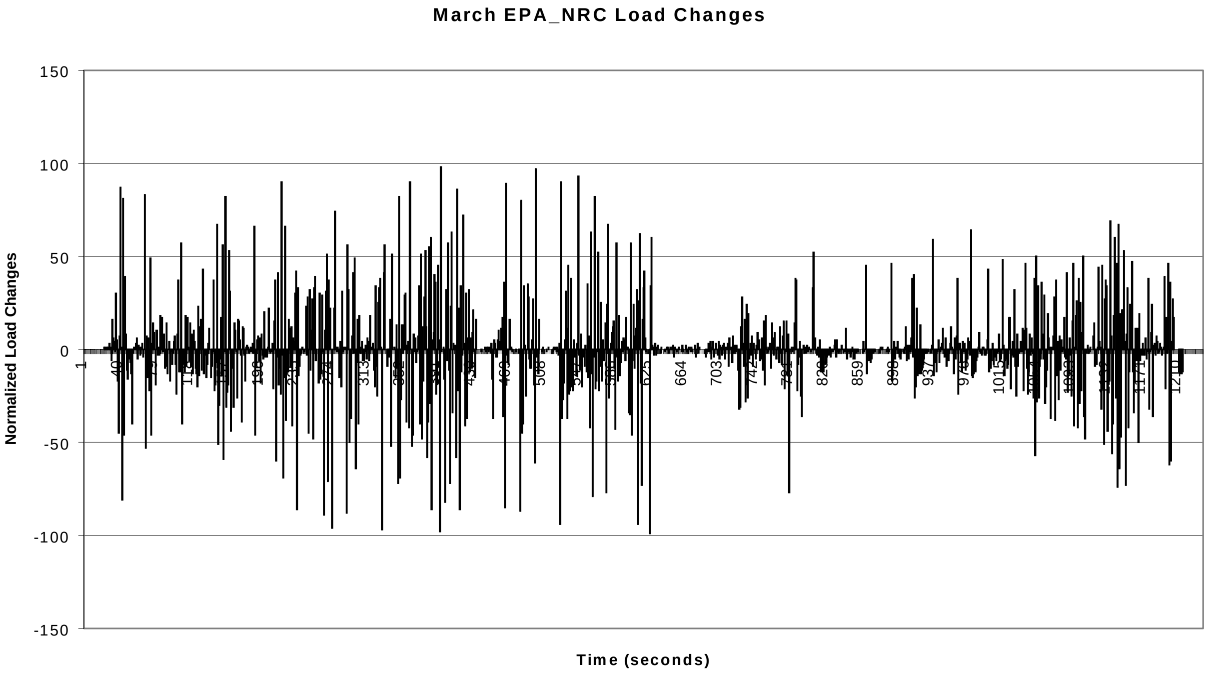


Figure 4.2-15

Average Load Changes of the EPA Generated NRTC



Given the modifications in the duty cycle, it was critical to assess the impact on the emissions signature of the cycle. The table below (Table

4.2-13) shows that the emissions signature, based on tests at the National Vehicle and Fuel Emissions Laboratory and at Southwest Research Institute as of May 2001, were relatively unchanged.

Table 4.2-13
Emissions and Cycle Regression Performance Summary as Presented to the Workgroup on June 1, 2001, at the Joint Research Center in Ispera, Italy

Caterpillar 3508	**NOx**		**PM**		**Speed**							
Heavy Duty	**Mean**	**Standard Dev.**	**Mean**	**Standard Dev.**	**SE**		**M**		**R2**		**B**	
850 hp					**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Sep-0C	10.30	0.02	0.20	0.004	79	1.41	1.03	0	0.949	0.001	-35	2.83
Mar-01	10.14	0.03	0.20	0.002	90	2.12	1.01	0.01	0.939	0.002	-9	3.54
JRC	11.198	0.03	0.20	0.004	68	0.71	1.03	0.00	0.962	0.001	-33	1.41

Torque								**Power**							
SE		**M**		**R2**		**B**		**SE**		**M**		**R2**		**B**	
Mean	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
15	0	0.8	0	0.734	0.004	184	0	14	0	0.88	0	0.801	0.283	29.6	0.283
15	0	0.83	0.007	0.734	0.001	188.5	3.54	14	0	0.9	0	0.804	0.002	29.5	1.273
12	0	0.91	0.007	0.765	0.001	56	1.41	11	0	0.95	0	0.823	0	6.1	0.141

Cummins ISB	**NOx**		**PM**		**Speed**							
Medium Duty	**Mean**	**Standard Dev.**	**Mean**	**Standard Dev.**	**SE**		**M**		**R2**		**B**	
					Mean	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Sep-00	3.76	0.01	0.08	0.001	54.7	24.62	0.987	0.011	0.987	0.010	30.0	3.11
Mar-01	3.79	0.03	0.08	0.003	68	18.67	0.98	0.01	0.982	0.008	32	14.48
JRC-Max Spd	4.06	0.03	0.08	0.002	66	6.22	0.98	0.00	0.978	0.005	34	5.23
JRC-ETC Pk Spd	4.09	0.01	0.08	0.009	50	8.15	0.98	0.00	0.991	0.003	37	6.68

Torque								**Power**							
SE		**M**		**R2**		**B**		**SE**		**M**		**R2**		**B**	
Mean	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
69.7	2.06	0.955	0.011	0.930	0.005	30.0	3.11	14.8	0.35	0.979	0.009	0.943	0.003	4.5	0.361
67.5	3.12	0.96	0.008	0.933	0.007	26.7	2.64	14.9	0.61	0.981	0.007	0.943	0.005	4.2	0.404
43.5	0.14	0.981	0.002	0.960	0.001	12.0	0.354	9.9	0.21	0.994	0.002	0.961	0.002	1.6	0.141
48.4	2.63	0.985	0.00306	0.946	0.005	11.6	1.386	10.0	0.68	0.999	0.002	0.958	0.005	1.6	0.265

As has been noted earlier in this chapter, the cycle was modified by EPA between September 2000 and March 2001 to address concerns related to the Arc Welder duty cycle segment of the NRTC. The modified EPA version was provided to JRC in early 2001, for its subsequent analysis, however not knowing the impact of the changes, all three cycles were tracked until the September 2000 version was eventually dropped.

In subsequent data submitted by engine manufacturers through December 5, 2001, the validity of the cycle from an emissions signature and test cell feasibility perspective was evidenced. Data submitted by Yanmar, Daimler Chrysler, Deere, Caterpillar, and Cummins to the JRC summary and analysis effort gave clear indication that the duty cycle could be run across multiple power ranges with good cycle performance results and consistent emissions signature[BB]. The cycle performance regression statistics would be defined based on nonroad engines, rather than adopting the highway performance statistics without review. The concern raised by Daimler Chrysler was that the cycle regression statistics needed to be sufficiently stringent to ensure an accurate and repeatable emissions

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[BB] Memorandum from Cleophas Jackson to EPA Air Docket A-2001-28, *JRC December 5, 2001, Report on Cycle Performance* signature was achieved[CC]. With the conclusion of the international workgroup's efforts, the cycle was considered complete by EPA. In an effort to facilitate the use of the cycle as a global nonroad transient duty cycle, it has been introduced into GRPE as a candidate cycle for the global compendium. The ISO procedure 8178-11 is being drafted to address test cell procedures for exercising an engine over the duty cycle. New limit values for the cycle performance regression statistics were developed as a part of this process and may be seen below in Table 4.2-14.

Table 4.2-14
NRTC Cycle Regression Statistics[154]

	Speed [rpm]	Torque [N·m]	Power [kW]
Regression Line Tolerances			
Standard Error of Estimate of Y on X	100 rpm	13% of power map maximum engine torque	8% of power map maximum
Slope of the regression line, m	0.95 to 1.03	0.83-1.03 (hot) 0.77-1.03 (cold)*	0.89-1.03 (hot) 0.87 -1.03 (cold)*
Coefficient of determination, r^2	min 0.970	min 0.8800 (hot) min 0.8500 (cold)*	min 0.9100 (hot) min 0.8500 (cold)
Y intercept of the regression line, b	± 50 rpm	± 20 N·m or ± 2.0% of max engine torque, whichever is greater	± 4 kW or ± 2.0% of max power, whichever is greater

* Under consideration by ISO workgroup.

4.2.9 Supplemental Cold Start Transient Test Procedure

We are proposing to include a requirement for a cold-start transient test to be run in conjunction with the hot-start run of the proposed transient test procedure. The proposed cold-start measurement is meant to recognize and quantify nonroad diesel engine missions generated for short periods at engine start-up. We further propose to weight these cold start emission results as 1/10 of total emissions, with the hot-start transient emissions making up the remainder. Cold start most often refers to nonroad engine emissions created during a short period after the first key-on event of the day, the first "cold start" for that piece of equipment in its workday. Given that the equipment has sat at ambient temperature for a minimum of six hours and in most cases overnight, engine startup will entail warming up the unit's operating and emission control equipment to normal operating temperatures. Likewise, a short period of engine operation, after a longer period of engine inactivity, may be characterized as having emissions similar to the earlier cold start operation as the unit must warm up its operating systems once more before running at peak efficiency. With this as background, EPA targeted the second-by-second operation of a population of some forty pieces of nonroad equipment for analysis to characterize the "average" workday of each unit and to determine if some portions of that workday were spent at a significantly higher rate of engine emissions than others. Generally, times when an engine is operating at cold start or less than stable operating temperature, frequently characterized by lower exhaust temperatures, engine emission rates can be seen to be higher than those during "warmer" engine operation.

[CC] Memorandum from Cleophas Jackson to EPA Air Docket A-2001-28, *Nonroad Transient Duty Cycle Development Report*, Cornetti, G., Hummel, R., and Jackson, C.

In one such analysis, EPA examined over 435 hours of second-by-second operating (actual "key-on" operation time) and NOx emission data from 13 pieces of construction equipment in the field[155] and is summarized in table 4.2-15 below.

Table 4.2-15

Portable Emissions Testing in a Construction Equipment Population

Equipment Type	Model Year	Total Cold-Start Key-on Periods	Total Operating Time (hr)	Cold-start NOx as Weighted Proportion of Total
Crawler Dozer	1999	11	25.85	0.038
Crawler Dozer	1985	4	30.53	0.021
Crawler Dozer	1987	11	31.72	0.065
Crawler Dozer	1988	10	41.87	0.025
Crawler Dozer	1990	6	20.86	0.042
Crawler Dozer	1995	7	49.29	0.018
Crawler Dozer	1998	8	49.16	0.037
Crawler Dozer	2001	12	63.09	0.032
Excavator	1989	8	20.48	0.062
Off-Highway Truck	1999	8	48.32	0.016
Off-Highway Truck	2001	7	26.20	0.053
Off-Highway Truck	2001	8	23.82	0.062
Wheel Loader	1983	7	4.41	0.097

All data was recorded in real time with EPA's Simple Portable On-board Testing emission monitoring equipment. The test population consisted of eight bulldozers, three sediment haulers, one excavator and one wheel loader. Each piece of equipment recorded one or two cold starts per workday. Cold starts included in its definition the first ten minutes of operation after the first "key-on" in a day and the first ten minutes of operation of that equipment after a period of an hour or more of inactivity within that same workday, as defined by the Julian date. Most of the crawler/dozers and the excavator exhibited three cold starts in a day and one dozer recorded four cold start periods in the same day. Grams of NOx were summed for all cold start periods for each piece of equipment per day and then divided by the total number of grams of NOx emitted from that piece of equipment for the entire "key-on" period of operation for that same day, giving the proportion of cold start statistic below.

$$p_{\mathrm{coldstart,day}} = \frac{\sum \mathrm{NO}x_{\mathrm{coldstarts}}}{\sum \mathrm{NO}x_{\mathrm{day}}}$$

where $\mathrm{NOx}_{\mathrm{coldstarts}}$ is the amount of NOx (g) emitted during the 10-minute cold-start periods during the day, and $\mathrm{NOx}_{\mathrm{day}}$ is the total amount of NOx (g) emitted during the day.

The proportion of NOx emissions from cold start operation for each day per piece of equipment, *P* above, was multiplied by the total time that that unit spent running for each day that the equipment had at least one "key-on". This statistic of the cold-start emissions proportion for a single workday for a single piece of equipment was then summed, and divided by the total time that piece of equipment spent in a "key-on" mode, i.e., running, over the course of the time that it was instrumented for study. This gives the time-weighted average of the proportion of NOx emitted during cold start periods over a work day.

$$p_{\mathrm{twa}} = \frac{\sum p_{\mathrm{coldstart,day}} \cdot t_{\mathrm{op,day}}}{\sum t_{\mathrm{op,day}}}$$

where p_{twa} is the time-weighted average of the cold-start proportion over all workdays and where $t_{\mathrm{op,day}}$ is the total operating time for a given day (hours).

This proportion ranged from 1.8% to 9.7% over all the sampled equipment, with an average value of 4.4%. The margin of error at a 95% confidence level (t-statistic) was +/- 1.4%.

Unresolved to date, is exactly what the rate of emissions from all pollutants might be in this population of construction units with respect to both cold starts and at-temperature operations. EPA has concerns that not all pollutants may be emitted at similar rates to those seen for NOx in this study. Likewise, given the breadth of nonroad equipment and application types that exist, EPA will not apply these results broadly to the nonroad equipment population but will use them as an indicator that, in fact, cold start operation may account for a significant amount of nonroad operating emissions over the course of a “typical” equipment workday. The time period over which these units were tested is significant, as well. The model years of the sampled equipment ranged from 1985 to 2001, and no piece of equipment was outfitted with either a diesel oxidation catalyst, PM filter trap or other such emission control equipment. In future years, such emission control equipment may be more common and the operating condition of the engine more a factor in when and how much pollutants are emitted during various periods of engine operation, e.g., cold start.

At cold start “key-on”, some units in this study were seen to operate at a slightly higher level of engine idle than the unit’s specified low-idle operation (approximately 10 percent higher engine speed)[156]. After a short period, usually five to ten minutes, these engines dropped back to low-idle speed operation. This type of operation, while the engine is still “cold”, may be a contributor to higher emission rates at start up for these engines, especially if higher exhaust temperatures will be needed in the first few minutes of operation for on-board emission control systems in these types of nonroad engines. In some of the equipment under EPA analysis, engine start up after periods of inactivity during a typical workday lasting sixty minutes or longer exhibited exhaust temperatures starting out below 100°C. Exhaust temperature remained under 150°C if the engine continued to operate at low idle, sometimes falling back below 100°C. Total “warm” engine operating emissions over the equipment’s workday hours will surpass the day’s “cold start” emissions by a large factor. However, a nonroad diesel engine which is designed to emit less at cold start will have lower emissions at other points in its operation as well and will on balance be a significantly cleaner engine in complying with cold start regulations.

4.2.10 Applicability of Component Cycles to Nonroad Diesel Market

We started to pursue application-specific operating duty cycles which could be normalized for laboratory testing of nonroad diesel engines in the 1997-1998 time frame. With a standardized set of operating duty cycles, we would have a basis upon which to compare the brake-specific emission rates of nonroad engines both within and across horsepower categories, or bands. These cycles became the component cycles of the NRTC cycle. The choice of the seven nonroad component application duty cycles was based on the frequency of finding engines of that particular mode of operation in the nonroad population and summing those with engines/equipment doing related work. Agricultural tractors were seen to have operations generally similar to combines, off-highway trucks and tractors. Arc welders represented the broad group of constant speed applications. The backhoe loader group included most of the lawn/garden/commercial turf tractors, commercial lifts and sweepers. The crawler/dozer application matched with other dozer, grader and scraper applications. Rubber-tire loaders were found to be similar to industrial and rough terrain forklifts, aircraft support and forestry equipment. Skidsteer loaders were seen, at the time, as a unique application/category. Finally, excavators and cranes were grouped together as similar applications. In time, the seven base nonroad equipment applications, agricultural tractor, arc welder, backhoe loader, crawler-dozer, excavator, rubber-tire loader and skidsteer loader were characterized for their daily operations and engine duty cycles were constructed for each type of work.

4.2.10.1 Market Representation of Component Cycles

The determination of which cycles would best represent the US nonroad equipment population was aided by an analysis of the our nonroad equipment population database.[157] Our source of data placed the total 1995 nonroad equipment population figure at 7,100,113 units in the U.S. The population broke out into at least 59 different equipment applications, or specific work categories. Agricultural tractors held the largest percentage by far at approximately 34% of units. Constant speed applications like generating sets, A/C and refrigeration units comprised a further 14%. Of the remaining pieces of the nonroad equipment, another 11% of the total population were engines which operated at a constant speed with varying load requirements like welders, air compressors and irrigation rigs. Commercial lawn and garden equipment made up an additional 7.5% of all units, with combines, backhoe and skidsteer loaders at 12%, each application adding a further 4% to the total population. In the approximately 20% of units remaining, rubber-tire loaders and crawler-dozers constituted 6% of all nonroad units, each contributing 3% to the nonroad population. Excavators and cranes comprised a little more than 2% of the total equipment population. The seven component application classesalone covered 51% of all nonroad equipment units. When "related" nonroad applications were grouped with the original seven applications, over 95% of the nonroad equipment population was represented by the component applications.

4.2.10.2 Inventory Impact of Equipment Component Cycles

When EPA created an emissions distribution from its database according to a list of the seven nonroad applications used to create the NRTC duty cycle, those seven base applications accounted for 59 percent of regulated nonroad engine emissions (see table 4.2-16 below).

Table 4.2-16
Emissions Attributable to Base Nonroad Applications

Application	Emission Distribution by Application
Ag tractor	34%
Welder	1%

Application	Emission Distribution by Application
Backhoe/loader	6%
Crawler	7%
Excavator	3%
R/T Loader	6%
Skid/steer	2%
Total	59%

4.2.10.3 HP and Sales Analysis

The nonroad equipment market is broad and varies in both range of power available and application, or intended use, of each piece of equipment. EPA's database was the source for the distribution of nonroad applications between the various engine power bands (by horsepower). Agricultural tractors, while accounting for fully a third of the nonroad equipment population, are built generally to smaller engine displacement specifications and so constituted only 20% of all nonroad horsepower in use. With similar equipment applications included, the equipment with an agricultural tractor-like horsepower number or displacement approaches 30 percent. Backhoe loaders, crawler dozers and rubber-tire loaders together accounted for 12 percent of the horsepower in the nonroad population and, with similar applications included, accounted for approximately 35 percent of total nonroad horsepower. The last three cycle component applications—excavators, skidsteer loaders and arc welders, with arc welders and like equipment generally falling into the 50 horsepower and under engine power band—constitute only 8 percent of total nonroad horsepower. However, because small constant speed engines exist in numerous applications, they also constitute a large number of discrete units in the nonroad population. This helps to explain their relatively large contribution (18%) as a group of similar applications to total nonroad horsepower. Taking the sum of horsepower represented by all applications similar to the seven component equipment applications found in the NRTC cycle, we have represented equipment operations and engine displacements and, by analogy, in-use operations of 91% of nonroad equipment units.

4.2.10.4 Broad Application Control

Aggregating all those equipment classifications whose operating characteristics were similar to the seven NRTC component cycles for their emission contributions, we found that the composite nonroad cycle covered emissions from almost 96% of the documented applications in the nonroad equipment population (see table 4.2-17 below).

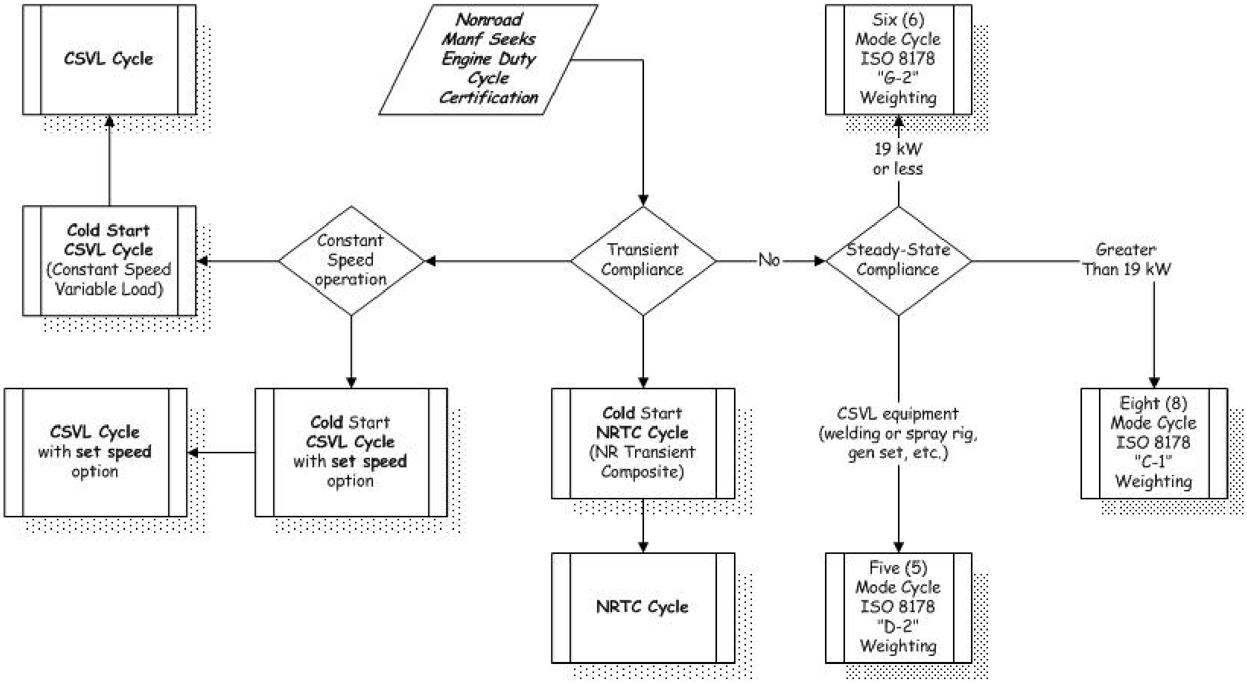
Table 4.2-17
Similarities Among Various Nonroad Equipment Applications

Application	Other Applications with Similar Operating Characteristics		Emission Distribution	Cycle characterization
Ag tractor	Combine Off-Hwy Tractor	Off-Hwy Truck	38.4%	Heavy-load operation along governor/lug curve
Welder	Air Compressors Gas Compressors Generators Pumps Bore/Drill Rigs Cement Mixers Chippers/Grinders Concrete/Ind. Saw Crush/Proc. Equip Hydr. Power Unit	Irrigation Sets Leaf Blow/Vacs Lt Plants/Signal Board Oil Fld Equip. Plate Compactors Pressure Washers Refrigeration/AC Shredder	25.2%	Transient loads at tightly governed rated speeds
Backhoe/loader	Aerial Lifts Comm. Turf Scrub/Sweeper Front Mowers	Lawn/Grdn. Tractor Rear Eng. Rider Specialty carts Terminal Tractor	13.5%	Widely varying loads and speeds, weighted toward lighter operation; most like highway operation
Crawler	Graders R/T Dozer	Scrapers Trenchers	5.7%	Widely varying loads and speeds, weighted toward heavier operation
Excavator	Cranes		2.4%	Transient loads at loosely governed rated speed
R/T Loader	Aircraft Support Forest Equip Forklifts	Rough Trn Fork.	6.7%	Stop and go driving with widely varying loads.
Skid/steer	—		3.6%	Widely varying loads at different nominally constant-speed points
Total			95.5%	

4.2.11 Final Certification Cycle Selection Process

Figure 4.2-16 below outlines the process by which a manufacturer of a particular nonroad diesel engine might approach certification and compliance of that engine with EPA’s proposed nonroad transient (and steady-state) test requirements.

Figure 4.2-16
Nonroad Diesel Engine Emission Testing Requirements



4.3 Feasibility of Not-to-Exceed Standards

EPA is proposing not-to-exceed (NTE) standards against which nonroad diesel engines are to be evaluated by using similar test procedures to those implemented as part of the highway diesel rule for MY 2007 and later heavy-duty engines.

However, EPA has also been exploring alternatives to the highway NTE test procedures for nonroad applications. These alternatives are detailed below. EPA believes that they show promise, especially for nonroad applications, because the unique characteristics of nonroad equipment have been considered when developing these procedures. Furthermore, we believe that these alternative procedures simplify on-vehicle testing, yet they maintain the same, if not better, level of compliance as compared to applying the highway procedures to nonroad applications. This alternative NTE's test procedure have been drafted in a dcoket memo entitled, "Changes Considered for §1065 Subpart J - Alternative NTE Field Test Procedures and Equipment.".[158]

4.3.1 What EPA concerns do all NTE standards address?

Regardless of the NTE test procedure, measuring emissions from engines as they undergo normal operation addresses two broad concerns. First, testing in-use engines has shown that emissions can vary dramatically under certain modes of operation and ambient conditions, which are not always easily replicated in a laboratory. NTE standards have a particular advantage because in contrast to lab standards, NTE standards are readily implementable in-use. NTE standards facilitate this because the standards are limits over a broad range of normal engine operation that may be measured on-vehicle. This may include varying engine speeds and loads according to real operation and may include a reasonable range of ambient and engine conditions. Second the contemplated Tier 4 nonroad standards anticipate the use of several emissions control technologies. NTE standards are one of the most realistic and cost effective means to measure emissions from field-aged engines. This helps ensure that emissions control systems are reliable for the useful life of an engine.

4.3.2 How does EPA characterize the highway NTE test procedures?

Refer to Chapter 4 of the Regulatory Impact Analysis of the highway HDDE rulemaking, published January 19, 2001 for details on the highway NTE test procedures. Briefly, the highway NTE provisions specify that averaging periods may be as short as 30 seconds in time, but under these provisions testing is also restricted to a very limited region of engine operation, namely when all of the following conditions are simultaneously met for at least 30 seconds (unless an aftertreatment system regenerates, then the minimum time would be longer):

1. Speed greater than 15% above idle speed
2. Torque greater than or equal to 30% of maximum torque
3. Power greater than or equal to 30% of maximum power
4. Altitude less than or equal to 5500ft (~>82kPa)
5. Ambient temperature less than or equal to 100F at sea level to 86F at 5500ft (30-38C)
6. BSFC less than or equal to 105% minimum BSFC if not coupled to a multi-speed manual or automatic transmissions
7. Outside of any manufacturer petitioned exclusion zone
8. Outside of any NTE region in which a manufacturer states that less than 5% of in-use time will be spent
9. Intake manifold temperature greater than or equal to 86-100F (20-30C), depending upon intake manifold pressure
10. Engine coolant temperature greater than or equal to 125-140F (52-60C), depending on intake manifold pressure.
11. Exhaust aftertreatment temperature greater than or equal to 250C.

4.3.3 How does EPA characterize the alternate NTE test procedures mentioned above?

The alternate NTE test procedure would apply to all normal engine operation regardless of speed-load combinations or a test period's frequency of idle, steady-state, or transient operation. This all-inclusive range of engine operation is consistent with EPA-collected data from nonroad vehicles and equipment. The alternate test procedure also requires only a few measured parameters, and this facilitates simple on-vehicle measurements. The data reduction procedure utilizes a "constant work" moving average that returns values weighted and calculated the same way that emissions data are reduced from a CVS test cell or from a weighted steady-state test. This provides an engineering target for manufacturers that is consistent with the FTP test procedures.

4.3.4 What limits might be placed on NTE compliance under the alternate test procedures?

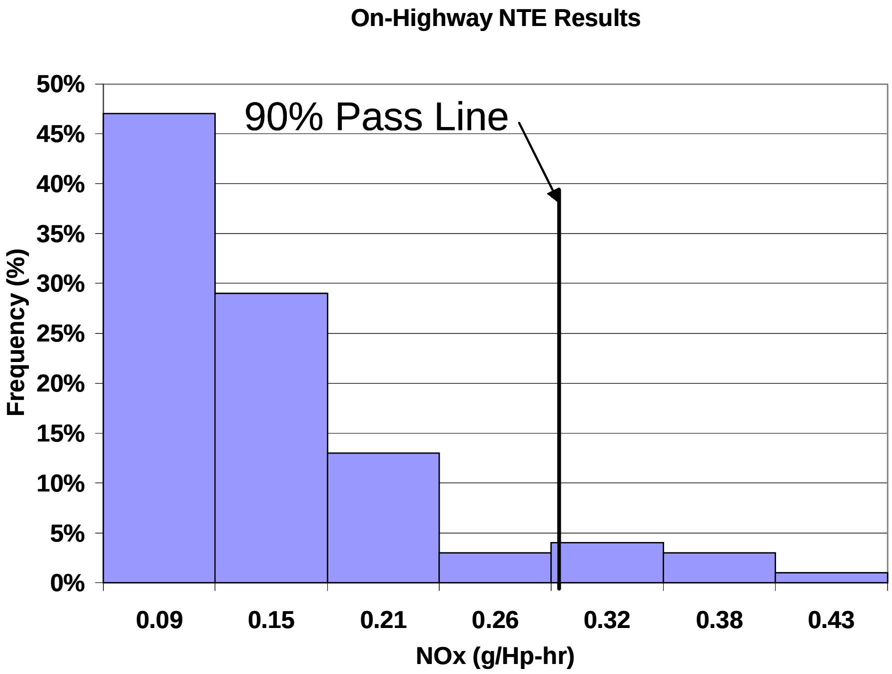
The alternate NTE test procedures would apply to all normal operation. This may include steady-state and/or transient engine operation. Given such NTE standards, the goal for the design engineer is to ensure that engines are properly calibrated for controlling emissions under any reasonably expected mode of engine operation. However, it may not be technologically feasible to meet specific NTE standards under all ambient and engine conditions so we will adopt some restrictions to narrow the range of ambient conditions and engine operation under which an engine is subject to the alternate NTE standards.

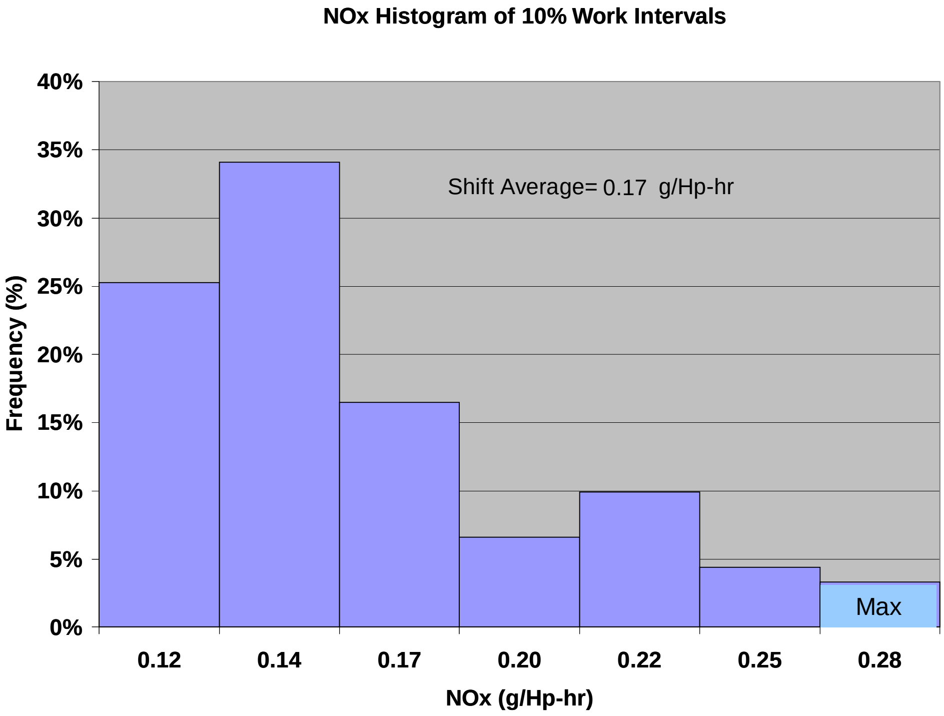
Engines are often designed to operate under extreme environmental conditions. To narrow the NTE range of compliance for the design engineer, we are limiting emission measurements for NTE testing to ambient temperatures up to +40˚ C, and to ambient pressures greater than or equal to 80.0 kPa. This allows testing over a wide range of conditions in addition to helping ensure that engines are able to control emissions under the range of conditions under which they are likely to operate. Because engine manufacturers already design entire engines to be reliable over an even wider range of ambient conditions, it is reasonable to expect that similar design information is already available to design low emissions engines that possess similar reliability with respect to emissions performance. Information on these extreme conditions are already required for proper design and construction of air intake systems, turbo-chargers, cooling systems, and lubricating systems.

And because of the catalysts expected to be utilized for NOx control, prolonged engine operation that is insufficient for catalyst heating will also be considered in the alternative NTE. The data reduction techniques for this is specified in the draft regulations in Appendix A. In summary, if any 10% work interval (described below) has a flow-weighted average exhaust temperature of less than 250C, then that interval’s NOx emissions must be no greater than 4.00 g/kw-hr.

Other important limits that the Agency has considered in order to define NTE standards are the averaging intervals and normalization procedures for data reduction. A longer averaging period allows for greater data stability, due mainly to the smoothing effect of measuring over several events. On the other hand, an overly long averaging period will likely mask areas of engine operation with poor emission-control characteristics. Even if poor emissions occurred over a relatively short period of a test, such high-emitting events may be indicative of a more serious deficiency once other engines have been determined to possess similar deficiencies. This is especially true if additional testing reveals that different in-use duty cycles cause the deficiency to result in poor emissions more frequently.

In order to maintain consistent NTE multipliers between the on-highway and alternate NTEs, similar on-highway and non-road data sets were analyzed using both procedures. The averaging scheme of the alternate NTE was adjusted so that both NTE concepts “passed” and “failed” similarly. Below is an example of such an analysis.





Analysis: The first chart depicts a histogram of the results by analyzing a real-world data set with the alternative NTE. Note that at an arbitrary FTP standard of 0.2 g/hp-hr, the 1.5x multiplier would result in a limit of 0.30 g/hp-hr. The alternative NTE reveals that the engine barely passes the

0.30 NTE standard with a maximum value of 0.28. Note too that the average is just below the FTP standard at 0.17 g/hp-hr. Now compare this to the same "barely passable" results returned by analyzing the data according to the on-highway NTE. Since the multiplier is the same between the two, one does observe that there is a small fraction of values greater than 0.30 in the highway NTE analysis. This fraction is just less than 10% however, so the analysis indicates just greater than 90% pass, which is part of the "pass" criteria outlined in the recent NTE settlement between EPA and some engine manufacturers. The highway NTE's analysis also shows that none of the data points is greater than 2x the NTE standard, which is also part of the settlement's "pass" criteria.

The alternate test procedure applies a "constant-work" moving average. In contrast to the highway NTE, the alternate NTE comprises of engine operation within the same ambient bounds–but at all speeds, loads, and BSFCs; there are neither manufacturer exclusion zones, nor exclusions based on intake or coolant conditions. For NOx emissions only there is one minimum exhaust temperature condition that needs to be met for a minimum duration. This results in a much more broad range of operation covered by the alternate NTE. This is justified because the large number of applications in the nonroad category (>6,000 different vehicle or equipment models) leads to a very broad range of probable engine operation. This is evidenced in EPA's and other global organization's composite non-road transient test cycles, and it is also obvious in the ~6,000 hours of non-road on-vehicle data that EPA collected during the years 2000 through 2002. Therefore, the alternate NTE procedure requires that all collected data, over all speeds and loads, will be included as part of the data reduction scheme.

4.3.5 How does the "constant-work" moving average work, and what does it do?

Since most engine operation will fall under the NTE standards, a sufficient emissions averaging period is required to determine if higher emissions during a specific speed-load combination is of significance. And because of the wide range of probable nonroad engine operation–including extended periods of idle operation–the alternate NTE procedures employ a "constant-work" moving average so that brake-specific emissions are not evaluated over short work intervals.

Specifically, the procedure specifies that an individual "test period" consists of a minium of six (6) hours engine-running operation. This test period is intended to be roughly consistent with a typical operator work-shift using nonroad equipment. Engine-off time would essentially be skipped until additional engine-running data can be merged with the previous engine-running data to continue data averaging. The work over this test period is totaled and it is normalized to a 6-hr shift if more than 6 hours of engine-running data was recorded. This means that if 8 hours were recorded, the total work would be divided by 8-hours and multiplied by 6-hours. The averaging interval is 10% of the normalized total work over the test period, and this 10% moving average will increment (or "move") at increments of 1% of the total work. This moving average will cause averages to overlap in time. This is desirable because it dampens the results' sensitivity to random combinations of speed and load being averaged together because of their proximity in time. This moving average scheme always returns at least 90 data points for comparison against the NTE standards. This reasonable number of data points, each consisting of a significant portion of a test period's work (10%), allows for the use of their maximum value to be compared to the NTE standards.

EPA analyzed several statistical methods to compare these results to an NTE standard. It was soon discovered that although the 90+ data points formed a convenient and continuous distribution of emissions values, the distribution's characteristics changed shape from one real-world data set to another. Some distributions seemed similar to normal or log-normal distributions, while others were greatly skewed with long tails on one end or another. This meant that parametric statistics based on a distributional assumption might be valid for one data set, but not on another. Therefore, statistics such as arithmetic means, geometric means, standard deviations, and confidence intervals were useful in some cases but not in all cases. Even powerful transformation algorithms were used in an attempt to de-skew some of the data sets, but even these failed in certain cases. One of the few alternatives for analyzing such data was to use non-parametric statistics, namely "tolerance intervals." In this case a significant number of data points are collected (90+), and based only on the fact that this number of points is collected, a level of confidence may be assigned as to whether the maximum emissions of the data set reflects the maximum possible emissions from the engine. For the case of these 90+ data points, non-parametric statistics suggest with 95% (+-4%) confidence that 95% of the engine's emissions are less than the maximum of the 90+ data points. This statistic is consistent with the intent of the NTE–it is a cap on the maximum allowable emissions. Note too that a 10% work interval, based on a 6-hr shift was selected not only to return this number of data points but also it was selected so that the NTE multipliers would be consistent with the highway multipliers.

There are several advantages to using the "constant-work" moving average approach. First, all moving average data points from a complete test period represent brake-specific emissions over the same work interval. This normalizes all of the data points so that they can be compared to each other in a meaningful way. NTE standards set for the maximum value of this data set is effective because the maximum of a set of significant (10% work) data points.

Note that this work-based normalization is similar to how an engine family is certified. A representative engine from a family is "mapped" to determine its maximum output at each engine speed, and this data set is used to "de-normalize" the certification test cycle so that the engine family is always run over the same test interval of work, no matter whether it is tested by a manufacturer, by an independent laboratory, or by EPA. This FTP constant work interval de-normalization also allows high power engines to be certified to the same brake-specific standard over the same time interval, but over a proportionally larger work interval. This element of certification testing is essential in order to normalize engine emissions so that engines of different rated power can be compared to the same brake-specific (e.g. work-specific) emissions standards.

In the alternate NTE the total in-use duty cycle of a 6 to12-hr test period is used to determine an appropriate work interval for the moving average of constant work. This use of a test period's total work essentially utilizes characteristic "real-world" total work to determine the appropriate (and constant) interval of work for data reduction. The total work of a test period will change from day-to-day, so individual data points from different days may not be directly comparable, even within a given engine family because the duty cycle on a given day will likely be different from another day. However, it is precisely this variable-duty-cycle element of in-use testing that EPA intends to preserve by using this data reduction scheme. By preserving this element of in-use testing, the engine is compared against its real-world duty cycle, not a fixed certification test cycle or fixed test work interval. This means that if an engine is tested under a qualitatively "high-load" test period, the work intervals will be of a higher work value but still varying time intervals. Nevertheless, the engine will be evaluated over a moving constant 10% work of that test period's total work. The opposite will also be true in that an engine evaluated over a "light-load" test period will be evaluated against lower work values of constant work that will still occur over varying time intervals.

Another advantage to this data reduction scheme is that within a given test period, random time intervals of relatively low power operation (i.e., idle) cause the work summing to take a longer time period to complete. By using 10% work intervals, idle operation is consistently averaged with other higher power output operation. This will always be true unless an in-use test period contains more than 10% of continuous work at idle. Because a diesel engine uses about seventy-five times as much fuel at rated power versus idle, this scenario is very unlikely. Before this could happen, the data reduction scheme would require that over half of the test period's time would have to be spent continuously, not intermittently, at idle in the case where the remainder of the test period averaged a 50% power duty-cycle. And if this were to be a real case, EPA would likely want to have such a significant idle operation evaluated against the NTE standards.

Any low power operation less continuous than the extreme case described above will be scaled relative to higher power operation because the field testing data reduction scheme "flow-weights" each constant work interval's emissions. This is exactly the same way constant-volume sampling (CVS) proportionally weights emissions during certification tests. Low-flow operation (i.e., idle) emissions are weighted proportionally less than other high-power emissions over a given work interval.

EPA has evaluated this data reduction scheme on several highway and nonroad in-use data sets collected from vehicles as they performed normal work in-use. We have determined that this data reduction scheme reduces the data into a reasonable number of meaningful data points that can be compared to the NTE standards in a consistent way. This data reduction scheme allows for the maximum 10%-work emissions to be compared to NTE standards, and it allows the entire test period's emissions to be compared to the FTP standard in a meaningful way.

4.3.6 What data would need to be collected in order to calculate emissions results using the alternate NTE?

Emissions volume concentrations (i.e., ppm or %) from the raw exhaust would need to be measured. These include total oxides of nitrogen ($NO + NO_2$), total hydrocarbons (THC), carbon monoxide (CO), and particulate matter mass (PM). THC needs to be converted to NMHC based on proposed regulation §1039.240(e). Particulate matter mass may be measured over other varying work intervals if a proportional integrating PM mass measurement technique is used rather than a PM mass concentration measurement. In order to flow-weight concentrations similar to CVS sampling, a signal linearly proportional to exhaust flow rate at standard conditions of 0 C, 101.325 kPa would need to be measured. This value does not need to be an absolute value in engineering units because the work calculation allows such unspecified units to be cancelled. Work may be calculated by first calculating fuel consumed via carbon balance. Since complete combustion is an appropriate assumption for diesel engines, fuel consumption may be determined by using carbon dioxide (CO_2) exhaust concentration multiplied by the signal proportional to exhaust flow. The fuel's atomic hydrogen-to-carbon ratio also needs to be factored into this calculation. This fuel consumption is then multiplied by the engine family's characteristic brake-specific fuel consumption to arrive at total work. For the alternate NTE, the characteristic brake-specific fuel consumption will be the arithmetic mean of the engine family's certification test cycles' brake-specific fuel consumptions. If an engine family is only certified to one test cycle, then its brake-specific fuel consumption over that test cycle will be the characteristic brake-specific fuel consumption for testing.

Using this characteristic brake-specific fuel consumption has several advantages. First it causes an engine family's characteristic certification efficiency to affect subsequent field-testing results. This causes an engine with poor certification fuel economy (high brake-specific fuel consumption), but favorable real-world fuel economy, to have proportionally higher emissions results during field testing. This effect is small (i.e., about 5%), but this characteristic should help to discourage manufacturers from designing low fuel economy solutions for meeting EPA certification tests; especially with the knowledge that the engine is not likely to see certification-type operation in use. According to recent manufacturer consent decrees this has resulted in low emissions and low fuel economy at certification, but high emissions and improved fuel economy during "off-cycle" operation. This off-cycle operation happened to occur frequently in-use, so that improved fuel economy was realized with the consequence of significantly higher in-use emissions. Second, by utilizing the characteristic certification efficiency, there is no requirement to measure engine output torque in-use. In fact the Agency believes such a requirement might be cumbersome because torque measurement may require attachment of a measurement device to the rotating output shaft, which may be close-coupled and sealed in a transmission housing. Additionally, nonroad engines sometimes have multiple output shafts, which would require multiple torque instrument installations; further complicating testing. Another advantage of using an average BSFC is that when measuring emissions at idle, a small amount of work is summed in the denominator of the emissions calculation. Because of the likelihood that nonroad engines are actually performing some work at idle by powering hydraulic, electric, or pneumatic accessories, this work should be included, and by using an average BSFC, it is included.

Other than emissions concentrations and exhaust flow, the only other required measurements would be those of ambient temperature and pressure for the purposes of determining if the data is collected within the range of applicable ambient conditions.

In conclusion, the measurement requirements will likely be minimal: emissions volume concentrations including CO_2, a signal linearly proportional to standard exhaust flow, ambient temperature, and ambient pressure.

4.3.7 Could data from a vehicle's on-board electronics be used to calculate emissions?

EPA will likely allow any data from a vehicle's on-board electronics to be used in the data reduction scheme, provided that it meets the data accuracy and precision requirements specified in the alternate NTE regulations. Additionally, the manufacturer would likely have to attest that such data meets these requirements at the time of NTE testing.

4.3.8 How would anyone test engines in the field?

To test engines without removing them from equipment, analyzers would be connected to the engine's exhaust to detect emission volume concentrations during normal operation. A signal linearly proportional to standard exhaust volumetric flow rate should also be measured to convert the analyzer responses to units of g/kW-hr for comparing to NTE standards. Ambient temperature and pressure would also have to be measured to determine if the NTE standards were applicable.

Available small analyzers and other equipment will likely be adapted for measuring emissions. A portable heated flame ionization detector (HFID) will likely be used to measure total hydrocarbon concentrations. A portable NDUV or Zirconia-based analyzer will likely be used to measure total NOx emissions. A nondispersive infrared (NDIR) analyzer will likely be used to measure CO and CO_2. Technologies such as a Tapered Element Oscillating Microbalance or a Quartz Crystal Microbalance will likely be used to inertially measure PM mass emissions.

Emission samples can best be drawn from the exhaust flow directly downstream from an aftertreatment system to avoid diluting effects from the end of the tailpipe. Installing a sufficiently long tailpipe extension will also likely be an acceptable way to avoid dilution.

4.3.9 How might in-use crankcase emissions be evaluated?

The anticipated crankcase emission-control technologies are best evaluated by visually checking if they continue to function as designed. A visual inspection of in-use engine crankcase emission-controls is appropriate to verify that these systems continue to function properly throughout useful life. Furthermore, as stated in the preamble to this proposed rulemaking in section III.B.2, manufacturers that choose not to utilize the closed crankcase approach for addressing crankcase emissions control would be responsible for ensuring that crankcase emissions would be readily measurable in use.

4.3.10 How might the agency characterize the technological feasability for manufacturers to comply with NTE standards?

The Agency acknowledges that compliance with NTE standards will require design engineers to better understand their engines’ emission behavior over a wide range of possible engine operation. Though claims have been made that NTE standards might be interpreted to cover a theoretically infinite degree of variability, we have determined that by evaluating a range of in-use duty cycles, a consistent level of control for any additional operation may be predicted. Making careful measurements over a statistically sound sampling plan provides reasonable certainty that any future emissions from an engine is likely to be within certain bounds. Such statistics are frequently used to ensure reliability of engine parts and engine performance, and we expect similar care to be taken when designing engines to meet NTE standards. We do not believe manufacturers will need to test an “infinite” or inappropriately large number of steady state and transient combinations. Rather, manufacturers will be able to quickly narrow their test programs to focus in on those areas of operation where the emissions are higher and come closer exceeding the NTE standards. Engineering experience and logic dictates that manufacturers will not expend resources testing areas where emissions are well understood and well below the NTE standards.

The same is true with respect to ambient conditions within the specified field-testing bounds. The effects of temperature and pressure on emissions are well known, so manufacturers may limit their testing to those ambient conditions that cause the highest emissions. Alternatively, manufacturers might choose to not test under conditions representing the endpoints of the established ranges, but rather they might test under “mid-range” conditions and rely on established extrapolation methods to ensure that their engines will meet emission standards when tested throughout the range of specified test conditions. If a manufacturer shows that engines meet emission standards under the most challenging conditions, then engines will meet the standards under less challenging conditions.

Because manufacturers have already demonstrated that they can build complex engines to be reliable for very many years beyond EPA's regulatory useful life, even when these engines have been operated throughout a wide range of extreme ambient conditions, the Agency believes that manufacturers can utilize already known design parameters and engineering and testing techniques to ensure that low emitting engines and aftertreatment systems are similarly reliable for emissions reductions at least throughout regulatory useful life and under similar conditions.

We also expect the manufacturers' statements at certification to state that they meet the NTE standards. These statements should be based on reasonable evidence of compliance, engineering analysis and good engineering judgment. We do not expect manufacturers to have tested every possible combination of points to be able to make their certifying statement.

In addition, we will put limits on the range of ambient conditions under which NTE standards might be evaluated. For example, during emission tests ambient air temperature must be between -0˚ C and 40˚ C and barometric pressure must be at least 80 kPa.

By restricting the NTE standards to "normal operation", we will likely allow manufacturers to include in engine designs any limitations applicable to normal operation. For example, if a manufacturer includes in the emission-related installation instructions a warning that the engine must not be installed to power a pump greater than some specific pumping rate, and takes steps to enforce that restriction, we would not consider such engine operation to be "normal operation" under the NTE standards. In some cases, manufacturers may also program their engines with a governor or other device to prevent engines from operating at certain speeds or loads.

Without NTE standards, we anticipate that some manufacturers might design their emission-control systems to function effectively only over the narrow range of engine operation and ambient conditions represented by the certification duty cycles. We feel that in these cases the NTE standards might be interpreted as increasing the overall stringency of the regulation. However, the basis for such a conclusion entirely depends upon a manufacturer's intended approach to meet emissions regulations. EPA has always intended for manufacturers to design solutions that ensure emissions control over a broad range of conditions and throughout useful life of an engine. Therefore, EPA believes that NTE standards do not increase the stringency of the overall regulation, but rather NTE standards ensure that engines are designed to meet the intention of the FTP standards.

In any case NTE standards evaluated via in-use testing will correspond directly with a more effective control of emissions from in-use engines as they undergo normal operation in nonroad applications. We also believe manufacturers will have available emission-control hardware (and software) that allows for more robust control over a wide range of operation and conditions. With some additional engineering, manufacturers can ensure that engines operate properly over the whole range of normal operation.

We already have equipment available to measure emissions using NTE procedures. Moreover, NTE standards take into account measurement tolerances and the variation in emissions due to varying engine operation and ambient conditions. Given the very active interest in portable measurement equipment in the rest of the industry, and given the lead time of this NPRM, we believe that measurement equipment will be widely available well ahead of time so that the NTE standards will likely apply to nonroad compression-ignition engines in 2011. We also believe that the measurement technology to meet the NTE standards is sufficiently known so that a technology review is not likely to be necessary.

In the early years of any such program, manufacturers are more likely to devote more of their effort to meet the NTE standards as they learn better how their engines behave under different types of operation. However, as they gain experience in designing robust emission-control systems by interpreting NTE test results, we would expect manufacturers to focus more on meeting the duty-cycle standards, knowing that emission variability has been controlled enough that the NTE standards no longer pose a significant additional constraint in their efforts to comply with all of the standards.

We have already set NTE standards for heavy-duty highway compression-ignition engines, large spark-ignition engines, and marine engines, and we believe that any proposed nonroad NTE standards take into account the unique aspects of operation and technology for nonroad compression-ignition engines. We believe that the information available today is ample to support our conclusions to propose NTE standards and field testing procedures for diesel nonroad engines.

We believe manufacturers will clearly do well by relying on these procedures to meet emission-testing requirements at a substantially lower cost than would be involved with laboratory testing.

The steady-state and transient test requirements clearly provide substantial assurance that engines will be controlling emissions under the kinds of operation seen when installed in the various types of nonroad equipment. We believe the NTE standards are an appropriate supplement to the duty-cycle standards for two reasons. First, any duty cycle, even one with transient engine operation cannot capture the whole range of “normal operation” from the multitude of different types of nonroad equipment. This may be especially important, since some of these engines might be operating in confined spaces where high emission levels pose a concern for individual exposures in addition to the more general issue of pollution in urban areas. The certification duty cycles will include many different combinations of speed, load, acceleration, and deceleration, but they cannot include or substantially weight the whole range of operation that engines may experience. This is underscored by in-use emission data generated to support the NTE standards. Second, without field-testing procedures, manufacturers would only be able to meet in-use testing requirements by removing engines from service and testing them in the laboratory.

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CHAPTER 6: Estimated Engine and Equipment Costs

This chapter discusses the various engine and equipment cost elements considered for the proposed emission standards and presents the total engine and equipment related costs we have estimated for compliance with the proposed new standards. First, in Section 6.1, a brief outline of the methodology used to estimate the engine and equipment cost impacts is presented. Next, in Sections 6.2 and 6.3, the projected costs of the individual technologies expected to be used to comply with the proposed standards are presented, along with a discussion of fixed costs such as research and development (R&D), tooling, certification, and equipment redesign. Section 6.4 summarizes these costs and presents all engine, equipment, and operating costs in a concise format. Section 6.5 then presents cost estimates for several example pieces of equipment. A complete presentation of the aggregate cost of compliance for engines and equipment is presented in Chapter 8 of this Draft RIA.

Note that we do not present any sensitivity analysis here. An analysis of sensitivity is presented in Chapter 9 where we present monetized benefits and social costs. Note also that the costs presented here do not include potential savings associated with our engine ABT program or our Transition Program for Equipment Manufacturers, because these are voluntary programs that, while we fully expect industry to use them to reduce compliance costs, they are not required to do so; all compliance costs presented here are for proposed regulatory requirements. Unless noted otherwise, all costs presented here are in 2001 dollars.

6.1 Methodology for Estimating Engine and Equipment Costs

This analysis makes a number of simplifying assumptions regarding how manufacturers would comply with the proposed standards. First, in each horsepower category, we assume a single technology recipe as discussed in detail in Chapter 4 of this Draft RIA. However, we expect that each manufacturer would evaluate all possible technology avenues to determine the one or ones that best balance costs while ensuring compliance. In addition, we fully expect manufacturers to make use of both the averaging, banking, and trading (ABT) program for engine manufacturers and the transition program for equipment manufacturers (TPEM) as a way to deploy varying degrees of emission control technologies on different engines and equipment. As noted, for developing cost estimates, we have assumed that the industry does not use either the TPEM or ABT programs, both of which offer the opportunity for significant cost reductions. Given these simplifying assumptions, we believe that the cost projections presented here provide a conservative cost estimate that probably overestimates the costs of the different approaches toward compliance that manufacturers may ultimately take.

For smaller nonroad engines – those under 75 horsepower – many of the technologies we expect would be needed for compliance would be applied for the first time. Therefore, we have sought input from a large section of the regulated community regarding the future costs that would be incurred to apply these technologies to diesel engines. Under contract from EPA, ICF

Consulting provided questions to several engine and parts manufacturers regarding costs associated with emission control technologies for diesel engines. The responses to these questions were used as a first step toward estimating the costs for many of the technologies we believe would be required for compliance. These costs form the basis for our estimated costs for “traditional” engine technologies such as EGR and fuel injection systems.[1]

Costs for exhaust emission control devices (e.g., catalyzed diesel particulate filters (CDPF), NOx adsorbers, and diesel oxidation catalysts (DOC)) were estimated using the methodology used in our 2007 HD highway diesel rulemaking. In that rulemaking effort, ICF Consulting, under contract to EPA, provided surveys to nine engine manufacturers seeking their estimates of the costs for and types of emission control technologies that might be enabled with low sulfur diesel fuel. The survey responses were used as the first step in estimating the costs for advanced emission control technologies we expected would be applied in order to meet the proposed 2007 heavy-duty diesel highway standards.[2] These costs were then further refined by EPA based upon input from members of the Manufacturers of Emission Controls Association. Because the exhaust emission control technologies expected for compliance with the proposed nonroad standards are the same as expected for highway engines, and because the suppliers of the technologies are the same for nonroad engines as for highway engines, we are using that analysis as the basis for our cost estimates here.

Costs of control include variable costs (for incremental hardware costs, assembly costs, and associated markups) and fixed costs (for tooling, R&D, and certification). For technologies sold by a supplier to the engine manufacturers, costs are either estimated based upon a direct cost to manufacture the system components plus a 29 percent markup to account for the supplier's overhead and profit or, when available, based upon estimates from suppliers on expected total costs to the manufacturers (inclusive of markups).[3] Estimated variable costs for new technologies include a markup to account for increased warranty costs. Variable costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer’s carrying cost was estimated to be four percent of the direct costs to account for the capital cost of the extra inventory and the incremental costs of insurance, handling, and storage. The dealer’s carrying cost was marked up three percent to account for the cost of capital tied up in inventory. This approach to estimating manufacturer and dealer markups to better reflect the value added at each stage of the cycle was adopted by EPA based on industry input.[4]

EPA has also identified various factors that would cause cost impacts to decrease over time, making it appropriate to distinguish between near term and long term costs. Research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts.[5] This analysis incorporates the effects of this learning curve as described in Section 6.2.2 of this chapter.

Fixed costs for engine R&D are estimated to be incurred over the five-year period preceding introduction of the engine. Fixed costs for tooling and certification are estimated to be incurred one year ahead of initial production. Fixed costs for equipment R&D/redesign are estimated to be incurred over a two year period preceding introduction of the piece of equipment, while equipment tooling costs are estimated to be incurred one year ahead of initial production. All fixed costs are increased by seven percent for every year before the start of production. Engine fixed costs are then "recovered" with a five-year amortization at the same rate except where a phase-in of a new standard occurs in which case the fixed costs are recovered during the phase-in years and then during the five years following 100 percent compliance.[A] Equipment fixed costs are recovered with a 10-year amortization at the same seven percent rate; the longer amortization period for equipment fixed costs reflects the longer product cycle for equipment. We have also included lifetime operating costs where applicable. These include costs associated with the higher cost fuel, potential fuel economy impacts, increased maintenance demands resulting from the addition of new emission control hardware, and expected savings associated with lower oil change maintenance costs as a result of the low sulfur fuel.

A simplistic overview of the methodology used to estimate engine and equipment costs would be as follows:

- For fixed costs (i.e., R&D, redesign, tooling, certification), we estimate the total dollars that industry will spend. We then calculate the total dollars that they will recover in each year of the program following implementation. These annual costs of recovery represent our estimate of fixed costs associated with the proposal. In Section 6.5 and in some engine-related fixed cost tables in Section 6.2.1, we also present an estimate of per-unit fixed costs. These per-unit fixed costs are impacted by the way we have broken up the horsepower categories in this cost analysis and by other factors (e.g., the engine prices we have estimated) as discussed in more detail below. Because we do not know how manufacturers would actually recover their costs on a per-unit basis, we present these per-unit fixed costs for informational purposes only. We do not use these per-unit fixed cost estimates in our cost per ton calculations; instead, we use the annual cost of recovery totals in the aggregate cost per ton calculations presented in Chapter 8 of this Draft RIA.

- For engine variable costs (i.e., emission control and associated hardware), we first estimate the cost per piece of technology. As described in detail in Section 6.2.2, emission control hardware costs tend to be directly related to engine characteristics – e.g., exhaust emission control devices are sized according to engine displacement so that costs vary by displacement; fuel injection systems vary in cost according to how many fuel injectors are required so that costs vary by number of cylinders. Therefore, we are able to determine a variable cost equation as a function of engine displacement or as a function of the number of

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[A] We have estimated a "recovered" cost for all engine and equipment fixed costs to present a per unit analysis of the cost of the proposal. In general, in environmental economics, it would be more conventional to simply count the total cost of the program (i.e., opportunity costs) in the year they occur. However, this approach would not directly estimate a per unit cost since fixed costs occur prior to implementation of the standards and, therefore, there are not yet any units certified as complying with the new standards to which the fixed costs can be attributed. As a result, we grow fixed costs until they can be "recovered" on complying units. Note that the approach used here results in a higher estimate of the total costs of the program since the recovered costs include a seven percent rate of return to the manufacturer.

cylinders. We then consider each unique engine's baseline technology package using a database of all nonroad equipment sold in the United States (U.S.).[6] That database lists engine characteristics for every one of over 7,000 pieces of equipment sold in the US and provides the sales of each piece of equipment. Using the current engine characteristics of each engine, the projected technology package for that engine, and the variable cost equations described in section 6.2, we calculate a variable cost for the engine in each of the over 7,000 pieces of equipment sold in the US. This variable cost per engine is then multiplied by that engine's projected sales in each year for the years following implementation of the new standards. We then total the annual costs for all engines to get the fleetwide variable costs per year. These fleetwide variable costs per year are then used in the cost per ton calculations presented in Chapter 8 of this draft RIA.

- Note that the cost per ton calculation is never impacted by how many horsepower categories we use in our cost analysis. We sometimes break up the fleet into more horsepower categories than would seem reasonable given the structure of the proposed standards. We do this for a couple of reasons: (1) phase-ins of standards and/or different levels of baseline versus proposed standards sometimes force such breakouts; and, (2) greater stratification (i.e., breaking up the 75 to 175 horsepower range and the 175 to 750 horsepower range) provides a better picture for use in our estimate of potential recovery of fixed costs. Importantly, the number of horsepower categories used does not impact the total costs estimated as a result of the proposed standards, and these total costs are the costs used to calculate a cost per ton number.

Engine costs are presented first – fixed costs, variable costs, then operating costs. Equipment costs follow – fixed costs then variable costs. A summation of engine and equipment costs follows these discussions. Variable cost estimates presented here represent an expected incremental cost of the engine or piece of equipment in the model year of introduction. Variable costs in subsequent years would be reduced by several factors, as described below. All costs are presented in 2001 dollars.

6.2 Engine-Related Costs

6.2.1 Engine Fixed Costs

6.2.1.1 Engine and Emission Control Device R&D

The technologies described in Chapter 4 of this Draft RIA represent those technologies we believe will be used to comply with the proposed Tier 4 emission standards. These technologies are also part of an ongoing research and development effort geared toward compliance with the 2007 heavy-duty diesel highway emission standards. Those engine manufacturers making R&D expenditures toward compliance with highway emission standards will have to undergo some R&D effort to transfer emission control technologies to engines they wish to sell into the nonroad market. These R&D efforts will allow engine manufacturers to develop and optimize these new technologies for maximum emission-control effectiveness with minimum negative impacts on engine performance, durability, and fuel consumption. However, many nonroad engine manufacturers are not part of the ongoing R&D effort toward compliance with highway emissions standards because they do not sell engines into the highway market. These manufacturers are expected to learn from the R&D work that has already occurred and will continue through the coming years through their contact with highway manufacturers, emission control device manufacturers, and the independent engine research laboratories conducting relevant R&D. Despite these opportunities for learning, we would expect the R&D expenditures for these nonroad-only manufacturers to be somewhat higher than for those manufacturers already conducting R&D in response to the HD2007 rule.

We are projecting that several technologies will be used to comply with the proposed Tier 4 emission standards. We are projecting that NOx adsorbers and CDPFs would be the most likely technologies applied by industry to meet our proposed emissions standards for >75 horsepower engines and, for engines between 25 and 75 horsepower, that CDPFs would be used in 2013 to meet the proposed PM standard. The fact that these technologies are being developed for implementation in the highway market prior to the implementation dates in today's proposal, and the fact that engine manufacturers would have several years before implementation of the proposed Tier 4 standards, ensures that the technologies used to comply with the nonroad standards would undergo significant development before reaching production. This ongoing development could lead to reduced costs in three ways. First, we expect research will lead to enhanced effectiveness for individual technologies, allowing manufacturers to use simpler packages of emission control technologies than we would predict given the current state of development. Similarly, we anticipate that the continuing effort to improve the emission control technologies will include innovations that allow lower-cost production. Finally, we believe that manufacturers would focus research efforts on any drawbacks, such as fuel economy impacts or maintenance costs, in an effort to minimize or overcome any potential negative effects.

We anticipate that, in order to meet the proposed standards, industry would introduce a combination of primary technology upgrades. Achieving very low NOx emissions would require basic research on NOx emission control technologies and improvements in engine management to take advantage of the exhaust emission control system capabilities. The manufacturers are expected to take a systems approach to the problem of optimizing the engine and exhaust emission control system to realize the best overall performance. Since most research to date with exhaust emission control technologies has focused on retrofit programs, there remains room for significant improvements by taking such a systems approach. The NOx adsorber technology in particular is expected to benefit from re-optimization of the engine management system to better match the NOx adsorber's performance characteristics. The majority of the dollars we have estimated for research is expected to be spent on developing this synergy between the engine and NOx exhaust emission control systems. Therefore, for engines requiring both a CDPF and a NOx adsorber (i.e., >75 horsepower), we have attributed two-thirds of the R&D expenditures to NOx control, and one-third to PM control.

In the 2007 highway rule, we estimated that each engine manufacturer would expend $35 million for R&D toward a successful implementation of catalyzed diesel particulate filters

(CDPF) and NOx adsorbers. For their nonroad R&D efforts on engines requiring CDPFs and NOx adsorbers (i.e., >75 horsepower), engine manufacturers selling into the highway market would incur some level of R&D effort but not at the level incurred for the highway rule. In many cases, the engines used by highway manufacturers in nonroad products are based on the same engine platform as those engines used in highway products. However, horsepower and torque characteristics are often different so some effort will have to be expended to accommodate those differences. Therefore, for these manufacturers, we have estimated that they would incur an R&D expense 10 percent of that incurred for the highway rule, or $3.5 million. This $3.5 million R&D expense would allow for the transfer of R&D knowledge from their highway experience to their nonroad engine product line. For reasons noted above, two-thirds of this R&D is attributed to NOx control and one-third to PM control.

For those manufacturers that sell engines only into the nonroad market, and where those engines require a CDPF and a NOx adsorber, we believe that they will incur an R&D expense nearing but not equaling that incurred by highway manufacturers for the highway rule. Nonroad manufacturers would be able to learn from the R&D efforts already underway for both the highway rule and for the Tier 2 light-duty highway rule (65 FR 6698). This learning could be done via seminars, conferences, and contact with highway manufacturers, emission control device manufacturers, and the independent engine research laboratories conducting relevant R&D. Therefore, we have estimated an expenditure of 70 percent of that spent by highway manufacturers in their highway efforts. This lower number—$24.5 million versus $35 million in the highway rule—reflects the transfer of knowledge to nonroad manufacturers from the many other stakeholders in the diesel industry. As noted above, two-thirds of this R&D is attributed to NOx control and one-third to PM control.

Note that the $3.5 million and $24.5 million estimates represent our estimate of the average R&D expected by manufacturers. These estimates would be different for each manufacturer – some higher, some lower – depending on product mix and the ability to transfer knowledge from one product to another.

For those engine manufacturers selling engines that would require CDPF-only R&D (i.e., 25 to 75 horsepower engines in 2013), we have estimated that the R&D they would incur would be roughly one-third that incurred by manufacturers conducting CDPF/NOx adsorber R&D. We believe this is a reasonable estimate because CDPF technology is further along in its development than is NOx adsorber technology and, therefore, a 50/50 split would not be appropriate. Using this estimate, the R&D incurred by manufacturers selling any engines into both the highway and the nonroad markets would be $1.2 million, and the R&D for manufacturers selling engines into only the nonroad market would be roughly $8 million. All of this R&D is attributed to PM control.

For those engine manufacturers selling engines that would require DOC-only or some engine-out modification R&D (i.e., to meet the PM standard on <75 horsepower engines in 2008), we have estimated that the R&D they would incur would be roughly one-half the amount estimated for their CDPF-only R&D. Application of a DOC should require very little R&D effort because these devices have been around for years and because they require no special fueling strategies or operating conditions to operate properly. Nonetheless, to be conservative we have estimated that the R&D incurred by manufacturers selling any engines into both the highway and nonroad markets would be roughly $600,000, and the R&D for manufacturers selling engines into only the nonroad market would be roughly $4 million. Because these R&D expenditures are strictly for meeting a PM standard, all of this R&D is attributed to PM control.

All of these R&D estimates are outlined in Table 6.2-1.

Table 6.2-1
Estimated R&D Expenditures by Type of Manufacturer
Totals per Manufacturer over Five Years

	R&D for CDPF&NOx Adsorber Engines	R&D for CDPF-only Engines	R&D for DOC/engine-out Engines
For proposed standards starting in year	2011 & 2012	2013	2008
Horsepower Range	hp≥75	25≤hp<75	0<hp<75
Manufacturer sells into both highway and nonroad markets	$3,500,000		$577,500
Manufacturer sells into only the nonroad market	$24,500,000		$4,042,500
Manufacturer has already done CDPF&NOx Adsorber R&D		$1,155,000	
Manufacturer has not done CDPF&NOx Adsorber R&D		$8,085,000	
% Allocated to PM	33%	100%	100%
% Allocated to NOx	67%		

To determine which manufacturers would incur which levels of R&D, we used certification data for the 2002 model year. Throughout this analysis, we have assumed that the manufacturers that certified engines for 2002 are the manufacturers under consideration for the proposed standards. When certifying engines, manufacturers project the sales of each engine they certify. This projected sales information is confidential business information and cannot be shared and, therefore, we cannot share our estimated R&D expenditures on a manufacturer by manufacturer basis.

Using the projected sales information, we were able to determine how many engine sales each manufacturer expects to have in each of the horsepower categories of interest. As a result, not every manufacturer is expected to incur all of the R&D costs shown in Table 6.2-1. For example, some manufacturers do not certify engines below 75 horsepower. Such a manufacturer would not incur R&D costs for CDPF-only engines or for those engines expected to add a DOC or make only engine-out changes. Also, some engine manufacturers produce and sell engines to specifications developed by other manufacturers. Such joint venture manufacturers or wholly owned manufacturers do not conduct engine-related R&D but simply manufacture an engine designed and developed by another manufacturer. For such manufacturers, we have assumed no engine R&D expenditures given that we believe they would conduct no R&D themselves and would rely on their joint venture partner. This is true unless the parent company has no engine sales in the horsepower categories covered by the partner company. Under such a situation, we have accounted for the necessary R&D by attributing it to the parent company. For example, Perkins is an engine manufacturer wholly owned by Caterpillar so we have attributed no R&D costs to Perkins. However, Perkins sells engines in horsepower categories that Caterpillar does not. As a result, we have attributed R&D costs to Caterpillar for conducting R&D that would benefit Perkins engines. We have identified nine manufacturers to whom we have attributed no R&D because of a joint partner agreement.[B] Some of these (e.g., Perkins) we have attributed R&D costs to their parent for the engines they will sell, and some are essentially the same company as their parent (e.g., Detroit Diesel and their parent DaimlerChrysler, New Holland and their parent CNH). In the end, it is not important to our analysis to what manufacturer the R&D is allocated because we have attempted to estimate the total R&D that would be spent by the entire industry.

We have also estimated that some manufacturers will choose not to invest in R&D for the U.S. nonroad market due to low volume sales that cannot justify the expense. We have identified three such manufacturers to whom we have attributed no R&D due to the cost of that R&D relative to our best estimate of their revenues.[C] This is not to say that we believe these manufacturers will cease to do business or even choose to leave the market; it only means that, given their low U.S. sales volumes, we believe it is unlikely that they would conduct the necessary R&D themselves. Instead, they would probably license the technology from another manufacturer which would serve to increase their own costs but reduce the net costs incurred by the licensing manufacturer; all while having no impact on the total costs of the rule. Because the determination of which manufacturers would and would not invest in R&D is based on projected sales data, we cannot share the manufacturer names. It is important to note that the total projected sales for all three engine manufacturers was 77 engines in the 2002 model year.

[B] Detroit Diesel and VM Motori were treated as part of DaimlerChrysler; IVECO, New Holland, and CNH were treated as one; Kirloskar and Kukje were treated as a partner of Cummins; Mitsubishi Motors Corporation and Mitsubishi Heavy Industries are treated as one company; Perkins R&D is attributed to Caterpillar; and, Volvo Construction Equipment and Volvo Penta AB are treated as one company.

[C] Estimated engine prices are shown in Table 6.2-3. We multiplied these prices by the manufacturer's projected sales volume to determine if projected revenues from engine sales would exceed our estimated R&D costs. If not, we have assumed that the manufacturer would not invest in the R&D and would, instead, license the R&D from another manufacturer. While this would result in costs to the licensing manufacturer, it would also result in profits to the licensor; therefore, it would not result in increased costs associated with the proposed standards.

Lastly, some certifying manufacturers do not appear to actually make engines. Instead, they purchase engines from another engine manufacturer and then certify it as their own. We have identified eight such certifying manufacturers and have attributed no R&D to these eight.[D]

Excluding the manufacturers we have identified as being in a joint partner arrangement or as unlikely to invest in R&D, there remain 20 manufacturers expected to invest in CDPF&NOx Adsorber R&D, 27 manufacturers expected to invest in CDPF-only R&D, and 28 manufacturers expected to invest in DOC/engine-out R&D. The total estimated R&D expenditures are shown in Table 6.2-2.

Table 6.2-2
Estimated Industrywide R&D Expenditures for the Proposed Nonroad Tier 4 Standards[a]

	DOC/engine-out R&D[b]	CDPF+NOx Adsorber R&D[b]	CDPF-only R&D[b]	Total R&D[b]
Expenditures during Years:	2003-2007	2006-2011	2008-2012	2003-2012
Horsepower	0<hp<75	≥75hp	25≤hp<75	all hp
Total Industry-wide R&D Expenditures	$36.0	$118.0	$45.2	$199.2
R&D for PM	$36.0	$38.9	$45.2	$120.1
R&D for NOx	—	$79.0	—	$79.0

[a] Dollar Values are in millions of 2001 dollars.
[b] Total R&D attributable to proposed U.S. standards (see discussion in text).

We have estimated that all engine-related R&D expenditures occur over a five year span preceding the first year any emission control device is introduced into the market. Those expenditures are then recovered by the engine manufacturer during any phase-in years and then over a five year span following introduction of the technology. As a result of the lack of PM phase-ins, most PM costs are recovered for five years following the first year of implementation. Most NOx costs are recovered over the two or three year phase-in and then five years following complete implementation, or a total of seven or eight years. We assume a seven percent rate of return for all R&D.

Our R&D estimates represent the cost to develop advanced aftertreatment based emission control systems enabled by <15 ppm sulfur diesel fuel. We are projecting that manufacturers would need to do this R&D to sell engines in Europe, Japan, Australia, and Canada because we expect that similar emission standards would be required on a similar timeframe for each of these regions or countries.[7] Therefore, we have attempted to attribute the costs of R&D to the total

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[D] These eight are: Alaska Diesel Electric; American Jawa; Eastern Tools and Equipment; Escorts, Ltd.; Harvest Drivemaster USA; International Tractors; Northern Tool and Equipment; Same Deutz-Fahr Group.

engine sales for these regions. Since we do not have sales data for every manufacturer showing what percent of their engines are sold in the US relative to these other regions, we have used Gross Domestic Product (GDP) as a surrogate for sales. As a result, we have attributed only a portion of the R&D expenditures to engine sales within the United States. Of the countries expected to have nonroad emission standards of similar stringency to our proposed standards, U.S. GDP constitutes 42 percent of the total.[E] Therefore, we have attributed 42 percent of the R&D costs to U.S. sales.

We have weighted R&D recovery according to estimated revenues for engines sold in each horsepower category. For example, CDPF&NOx Adsorber R&D benefits all engines above 75 horsepower. However, engines above 175 horsepower must introduce the new technologies in 2011, while engines from 75 to 175 horsepower would introduce it a year later. As a result, R&D costs are assumed to be recovered on >175 horsepower engines between 2011 and 2015/2018 and on 75 to 175 horsepower engines between 2012 and 2016/2018. Delaying implementation dates for these engines, or a subset of these engines, would not impact our estimated R&D expenditures or their recovery but would, instead, only affect the timing of their recovery. To weight the costs between engines in these categories, we have used revenue weighting rather than a more simplistic sales weighting under the belief that manufacturers would attempt to recover more costs where more revenues occur. Revenue weighting is simply an estimated price multiplied by a unit sales figure. The revenue weightings we have used are shown in Table 6.2-3.

Using this methodology, we have estimated the total R&D expenditures attributable to the proposed standards at $7 to $33 million per year depending on the year, with an average of $18 million per year and a total of $199 million. Total R&D recovery on U.S. sales is estimated at $279 million. All estimated R&D costs are shown in Table 6.2-4. Note that the engine sales numbers shown in Table 6.2-4 are discussed in greater detail in Chapter 8 of this Draft RIA where we present aggregate costs to society.

[E] According to the Worldbank, in 2000, the European countries of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, and the United Kingdom had a combined GDP of $7.8B; Australia’s GDP was $0.4B; Canada’s GDP was $0.7B; Japan’s GDP was $4.7B; and the U.S. GDP was $9.9B; for a total GDP of $23.5B (www.worldbank.org).

Table 6.2-3
Revenue Weightings Used to Allocate R&D Cost Recovery

Horsepower	2000 Sales	Estimated Engine Price	Revenue Weighted Recovery of R&D in the Indicated Years				
			PM	2008-2012	2011-2015	2012-2016	2013-2017
			NOx	N/A	2011-2018	2012-2018	N/A
0<hp<25	119,159	$1,500		22%			
25≤hp<50	132,981	$2,800		46%			59%
50≤hp<75	93,914	$2,800		32%			41%
75≤hp<100	68,665	$5,000				11%	
100≤hp<175	112,340	$5,000				17%	
175≤hp<300	61,851	$10,000			26%	19%	
300≤hp<600	34,095	$30,000			44%	32%	
600≤hp≤750	2,752	$125,000			15%	10%	
hp>750	2,785	$125,000			15%	11%	
Total	628,542			100%	100%	100%	100%

Table 6.2-4

Estimated R&D Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2001

Thousands of dollars, except per engine values

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
0<hp<25	Estimated US Sales	131,507	135,623	139,739	143,855	147,971	152,087	156,203	160,319	164,435	168,551	172,667	176,783	180,899	185,015	189,131	193,247	193,247	193,247	
	PM Costs Incurred	$1,581	$1,581	$1,581	$1,581	$1,581														$7,905
	NOx Costs Incurred																			$0
	PM Costs Recovered						$2,218	$2,218	$2,218	$2,218	$2,218									$11,088
	NOx Costs Recovered																			$0
	Per Engine Cost						$15	$14	$14	$13	$13									
25<=hp<50	Estimated US Sales	143,496	147,001	150,506	154,011	157,516	161,021	164,526	168,031	171,536	175,041	178,546	182,051	185,556	189,061	192,566	196,071	196,071	196,071	
	PM Costs Incurred	$3,294	$3,294	$3,294	$3,294	$3,294	$5,304	$5,304	$5,304	$5,304	$5,304									$42,988
	NOx Costs Incurred																			$0
	PM Costs Recovered						$4,620	$4,620	$4,620	$4,620	$4,620	$7,439	$7,439	$7,439	$7,439	$7,439				$60,294
	NOx Costs Recovered																			$0
	Per Engine Cost						$29	$28	$27	$27	$26	$42	$41	$40	$39	$39				
50<=hp<75	Estimated US Sales	100,051	102,097	104,142	106,188	108,234	110,279	112,325	114,371	116,416	118,462	120,507	122,553	124,599	126,644	128,690	130,736	130,736	130,736	
	PM Costs Incurred	$2,326	$2,326	$2,326	$2,326	$2,326	$3,746	$3,746	$3,746	$3,746	$3,746									$30,359
	NOx Costs Incurred																			$0
	PM Costs Recovered						$3,262	$3,262	$3,262	$3,262	$3,262	$5,254	$5,254	$5,254	$5,254	$5,254				$42,581
	NOx Costs Recovered																			$0
	Per Engine Cost						$30	$29	$29	$28	$28	$44	$43	$42	$41	$41				
75<=hp<100	Estimated US Sales	73,162	74,662	76,161	77,660	79,159	80,659	82,158	83,657	85,157	86,656	88,155	89,654	91,154	92,653	94,152	95,652	95,652	95,652	
	PM Costs Incurred					$825	$825	$825	$825	$628										$3,929
	NOx Costs Incurred					$838	$838	$1,676	$1,676	$1,016	$838	$838								$7,718
	PM Costs Recovered										$1,158	$1,158	$1,158	$1,158	$880					$5,510
	NOx Costs Recovered										$1,175	$1,175	$2,350	$2,350	$1,425	$1,175	$1,175			$10,825
	Per Engine Cost										$27	$26	$39	$38	$25	$12	$12			
100<=hp<175	Estimated US Sales	119,303	121,625	123,946	126,267	128,588	130,909	133,230	135,551	137,872	140,193	142,514	144,836	147,157	149,478	151,799	154,120	154,120	154,120	
	PM Costs Incurred					$1,350	$1,350	$1,350	$1,350	$1,027										$6,428
	NOx Costs Incurred					$1,371	$1,371	$2,741	$2,741	$1,662	$1,371	$1,371								$12,627
	PM Costs Recovered										$1,894	$1,894	$1,894	$1,894	$1,440					$9,015
	NOx Costs Recovered										$1,922	$1,922	$3,845	$3,845	$2,331	$1,922	$1,922			$17,711
	Per Engine Cost										$27	$27	$40	$39	$25	$13	$12			
175<=hp<300	Estimated US Sales	66,093	67,507	68,921	70,335	71,749	73,163	74,577	75,991	77,405	78,819	80,233	81,647	83,061	84,475	85,889	87,303	87,303	87,303	
	PM Costs Incurred				$1,625	$1,487	$1,487	$1,487	$1,487											$7,572
	NOx Costs Incurred				$1,650	$1,509	$1,509	$3,019	$3,019	$1,830	$1,509	$1,509								$15,554
	PM Costs Recovered									$2,279	$2,085	$2,085	$2,085	$2,085						$10,620
	NOx Costs Recovered									$2,314	$2,117	$2,117	$4,234	$4,234	$2,567	$2,117	$2,117			$21,815
	Per Engine Cost									$59	$53	$52	$77	$76	$30	$25	$24			
300<=hp<600	Estimated US Sales	35,403	35,839	36,275	36,711	37,147	37,583	38,019	38,455	38,891	39,327	39,763	40,199	40,635	41,071	41,507	41,943	41,943	41,943	
	PM Costs Incurred				$2,687	$2,459	$2,459	$2,459	$2,459											$12,522
	NOx Costs Incurred				$2,728	$2,496	$2,496	$4,992	$4,992	$3,026	$2,496	$2,496								$25,722
	PM Costs Recovered									$3,769	$3,449	$3,449	$3,449	$3,449						$17,563
	NOx Costs Recovered									$3,826	$3,501	$3,501	$7,002	$7,002	$4,245	$3,501	$3,501			$36,077
	Per Engine Cost									$195	$177	$175	$260	$257	$103	$84	$83			
600<=hp<=750	Estimated US Sales	2,902	2,952	3,002	3,052	3,102	3,152	3,202	3,252	3,302	3,352	3,402	3,452	3,502	3,552	3,602	3,652	3,652	3,652	
	PM Costs Incurred				$904	$827	$827	$827	$827											$4,211
	NOx Costs Incurred				$917	$839	$839	$1,679	$1,679	$1,018	$839	$839								$8,651
	PM Costs Recovered									$1,268	$1,160	$1,160	$1,160	$1,160						$5,907
	NOx Costs Recovered									$1,287	$1,177	$1,177	$2,355	$2,355	$1,428	$1,177	$1,177			$12,133
	Per Engine Cost									$774	$697	$687	$1,018	$1,004	$402	$327	$322			
>750hp	Estimated US Sales	2,938	2,989	3,040	3,091	3,142	3,193	3,244	3,295	3,346	3,397	3,448	3,499	3,550	3,601	3,652	3,703	3,703	3,703	
	PM Costs Incurred				$915	$837	$837	$837	$837											$4,262
	NOx Costs Incurred				$928	$850	$850	$1,699	$1,699	$1,030	$850	$850								$8,755
	PM Costs Recovered									$1,283	$1,174	$1,174	$1,174	$1,174						$5,978
	NOx Costs Recovered									$1,302	$1,191	$1,191	$2,383	$2,383	$1,445	$1,191	$1,191			$12,279
	Per Engine Cost									$773	$696	$686	$1,016	$1,002	$401	$326	$322			
All hp	PM Costs Incurred	$7,201	$7,201	$7,201	$13,331	$14,986	$16,835	$16,835	$16,835	$10,704	$9,050									$120,177
	NOx Costs Incurred				$6,223	$7,903	$7,903	$15,805	$15,805	$9,582	$7,903	$7,903								$79,027
	Total Costs Incurred	$7,201	$7,201	$7,201	$19,555	$22,888	$24,737	$32,640	$32,640	$20,286	$16,952	$7,903								$199,204
	PM Costs Recovered						$10,100	$10,100	$10,100	$18,698	$21,018	$23,611	$23,611	$23,611	$15,013	$12,693				$168,555
	NOx Costs Recovered									$8,729	$11,084	$11,084	$22,168	$22,168	$13,439	$11,084	$11,084			$110,839
	Total Costs Recovered						$10,100	$10,100	$10,100	$27,427	$32,102	$34,695	$45,779	$45,779	$28,452	$23,777	$11,084			$279,394

6.2.1.2 Engine-Related Tooling Costs

Once engines are ready for production, new tooling will be required to accommodate the assembly of the new engines. In the 2007 highway rule, we estimated approximately $1.6 million per engine line for tooling costs associated with CDPF/NOx adsorber systems. For the proposed nonroad Tier 4 standards, we have estimated that nonroad-only manufacturers would incur the same $1.6 million per engine line requiring a CDPF/NOx adsorber system and that these costs would be split evenly between NOx control and PM control. We have estimated the same tooling costs as estimated in the 2007 highway rule because we expect these Tier 4 engines would use the same technologies as the 2007 highway rule (i.e., a CDPF and a NOx adsorber). For those systems requiring only a CDPF, we have estimated one-half that amount, or $800,000 per engine line. For those systems requiring only a DOC or some engine-out modifications, we have estimated one-half the CDPF-only amount, or $400,000 per engine line. Tooling costs for CDPF-only and for DOC engines are attributed solely to PM control.

For those manufacturers selling into both the highway and nonroad markets, we have started with the same $1.6 million baseline discussed above. For those engines requiring a CPDF/NOx adsorber system (i.e., those >75 horsepower) we have adjusted that $1.6 million baseline by 50 percent. We believe this 50 percent adjustment is reasonable since many nonroad engines over 75 horsepower are produced on the same engine line with their highway counterparts. For such lines, essentially no tooling costs would be incurred. For engine lines without a highway counterpart, the $1.6 million tooling cost would be applicable. For highway manufacturers selling into both the highway and the nonroad markets, we have assumed a 50/50 split of nonroad engine product lines (i.e., 50 percent with highway counterparts and 50 percent without) and, therefore, a 50 percent factor applied to the $1.6 million baseline. These tooling costs would be split evenly between NOx control and PM control. For those engine lines requiring only a CDPF (i.e., those between 25 and 75 horsepower), we have estimated the same tooling cost as used for nonroad-only manufacturers, or $800,000. Similarly, the tooling costs for DOC and/or engine-out engine lines has been estimated to be $400,000. We have used the same tooling costs as the nonroad-only manufacturers for the <75 horsepower engines because these engines tend not to have a highway counterpart. Tooling costs for CDPF-only and for DOC engines are attributed solely to PM control.

We have projected that engines in the 25 to 50 horsepower range would apply EGR systems to meet the proposed NOx standards for 2013. For these engines, we have included an additional tooling cost of $40,000 per engine line, consistent with the EGR-related tooling cost estimated for 50-100 horsepower engines in our Tier 2/3 rulemaking where the same NOx standards was required. This tooling cost is applied equally to all engine lines in that horsepower range regardless of the markets into which the manufacturer sells. We have applied this tooling cost equally because engines in this horsepower range do not tend to have highway counterparts. Because EGR systems are expected to be added to engines between 25 and 50 horsepower to meet the proposed NOx standard, tooling costs for EGR systems are attributed solely to NOx control.

Tooling costs per engine line and type of manufacturer are summarized in Table 6.2-5.

Table 6.2-5
Estimated Tooling Expenditures per Engine Line by Type of Manufacturer

	DOC/engine-out Engines	CDPF-only Engines	CDPF & NOx Adsorber Engines	EGR Engines
Horsepower Range	0<hp<75	25≤hp<75	hp≥75	25≤hp<50
For proposed standards starting in	2008	2013	2011/2012	2013
Manufacturer sells into both highway & nonroad markets	$400,000	$800,000	$800,000	$40,000
Manufacturer sells into only the nonroad market	$400,000	$800,000	$1,600,000	$40,000
% Allocated to PM	100%	100%	50%	0%
% Allocated to NOx	0%	0%	50%	100%

As noted, we have applied tooling costs by engine line assuming that engines in the same line are produced on the same production line. Typically, the same basic diesel engine design can be increased or decreased in size by simply adding or subtracting cylinders. As a result, a four, six, eight, etc., cylinder engine may be produced from the same basic engine design. While these engines would have different displacements, the added or subtracted cylinders would have the same displacement per cylinder. Using the PSR database, we grouped each engine manufacturer’s engines into distinct engine lines using increments of 0.5 liters per cylinder. This way, engines having similar displacements per cylinder are grouped together and are considered to be built on the same production line. Note that a tooling expenditure for a single engine line may cover engines over several horsepower categories. To allocate the tooling expenditure for a given production line to a specific horsepower range, we have used sales weighting within that engine line.

We have applied all the above tooling costs to all manufacturers that appear to actually make engines. We have not eliminated joint venture manufacturers because these manufacturers would still need to invest in tooling to make the engines even if they do not conduct any R&D. Doing this, we determined there to be 62 manufacturers expected to invest in tooling for a total of 133 engine lines. Of these, 19 manufacturers sell into both the highway and nonroad markets and sell a total of 56 engine lines, while 43 manufacturers sell into only the nonroad market and sell a total of 77 engine lines. For the same reasons as explained for R&D costs, we have attributed a portion of the tooling costs to U.S. sales and a portion to sales in other countries expected to have similar levels of emission control. All tooling costs are assumed to be incurred one year prior to the standard they support and are then recovered over a five year period following introduction of the new standard. For engines >750 hp, half of the tooling costs are incurred one year ahead of 2011 and the other half are incurred one year ahead of 2014 due to the 50/50/50/100 percent phase-in that begins in 2011. The costs are then recovered over an eight year period due to this phase-in. A seven percent interest rate is used to account for the time value of money.

Using this methodology, we estimate the total tooling expenditures attributable to the proposed standards at $67 million. Total tooling recovery on U.S. sales is estimated at $81 million. All estimated tooling costs are shown in Table 6.2-6.

Table 6.2-6

Estimated Tooling Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2001

Thousands of dollars, except per engine values

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
0<hp<25	Estimated US Sales	147,971	152,087	156,203	160,319	164,435	168,551	172,667	176,783	180,899	185,015	189,131	193,247	193,247	
	PM Costs Incurred	$3,365													$3,365
	NOx Costs Incurred														$0
	PM Costs Recovered		$821	$821	$821	$821	$821								$4,104
	NOx Costs Recovered														$0
	Per Engine Cost		$5	$5	$5	$5	$5								
25<=hp<50	Estimated US Sales	157,516	161,021	164,526	168,031	171,536	175,041	178,546	182,051	185,556	189,061	192,566	196,071	196,071	
	PM Costs Incurred	$3,756					$4,148								$7,903
	NOx Costs Incurred						$506								$506
	PM Costs Recovered		$916	$916	$916	$916	$916	$1,012	$1,012	$1,012	$1,012	$1,012			$9,638
	NOx Costs Recovered							$123	$123	$123	$123	$123			$616
	Per Engine Cost		$6	$6	$5	$5	$5	$6	$6	$6	$6	$6			
50<=hp<75	Estimated US Sales	108,234	110,279	112,325	114,371	116,416	118,462	120,507	122,553	124,599	126,644	128,690	130,736	130,736	
	PM Costs Incurred	$2,652					$2,929								$5,582
	NOx Costs Incurred														$0
	PM Costs Recovered		$647	$647	$647	$647	$647	$714	$714	$714	$714	$714			$6,806
	NOx Costs Recovered														$0
	Per Engine Cost		$6	$6	$6	$6	$5	$6	$6	$6	$6	$6			
75<=hp<100	Estimated US Sales	79,159	80,659	82,158	83,657	85,157	86,656	88,155	89,654	91,154	92,653	94,152	95,652	95,652	
	PM Costs Incurred					$2,685									$2,685
	NOx Costs Incurred					$2,685									$2,685
	PM Costs Recovered						$655	$655	$655	$655	$655				$3,274
	NOx Costs Recovered						$655	$655	$655	$655	$655				$3,274
	Per Engine Cost						$15	$15	$15	$14	$14				
100<=hp<175	Estimated US Sales	128,588	130,909	133,230	135,551	137,872	140,193	142,514	144,836	147,157	149,478	151,799	154,120	154,120	
	PM Costs Incurred					$4,392									$4,392
	NOx Costs Incurred					$4,392									$4,392
	PM Costs Recovered						$1,071	$1,071	$1,071	$1,071	$1,071				$5,356
	NOx Costs Recovered						$1,071	$1,071	$1,071	$1,071	$1,071				$5,356
	Per Engine Cost						$15	$15	$15	$15	$14				
175<=hp<300	Estimated US Sales	71,749	73,163	74,577	75,991	77,405	78,819	80,233	81,647	83,061	84,475	85,889	87,303	87,303	
	PM Costs Incurred				$10,665										$10,665
	NOx Costs Incurred				$10,665										$10,665
	PM Costs Recovered					$2,601	$2,601	$2,601	$2,601	$2,601					$13,006
	NOx Costs Recovered					$2,601	$2,601	$2,601	$2,601	$2,601					$13,006
	Per Engine Cost					$67	$66	$65	$64	$63					
300<=hp<600	Estimated US Sales	37,147	37,583	38,019	38,455	38,891	39,327	39,763	40,199	40,635	41,071	41,507	41,943	41,943	
	PM Costs Incurred				$5,879										$5,879
	NOx Costs Incurred				$5,879										$5,879
	PM Costs Recovered					$1,434	$1,434	$1,434	$1,434	$1,434					$7,169
	NOx Costs Recovered					$1,434	$1,434	$1,434	$1,434	$1,434					$7,169
	Per Engine Cost					$74	$73	$72	$71	$71					
600<=hp<=750	Estimated US Sales	3,102	3,152	3,202	3,252	3,302	3,352	3,402	3,452	3,502	3,552	3,602	3,652	3,652	
	PM Costs Incurred				$475										$475
	NOx Costs Incurred				$475										$475
	PM Costs Recovered					$116	$116	$116	$116	$116					$579
	NOx Costs Recovered					$116	$116	$116	$116	$116					$579
	Per Engine Cost					$70	$69	$68	$67	$66					
>750hp	Estimated US Sales	3,142	3,193	3,244	3,295	3,346	3,397	3,448	3,499	3,550	3,601	3,652	3,703	3,703	
	PM Costs Incurred				$253			$253							$506
	NOx Costs Incurred				$253			$253							$506
	PM Costs Recovered					$62	$62	$62	$123	$123	$62	$62	$62		$616
	NOx Costs Recovered					$62	$62	$62	$123	$123	$62	$62	$62		$616
	Per Engine Cost					$37	$36	$36	$70	$69	$34	$34	$33		
All hp	PM Costs Incurred	$9,773			$17,271	$7,077	$7,077	$253							$41,451
	NOx Costs Incurred				$17,271	$7,077	$506	$253							$25,107
	Total Costs Incurred	$9,773			$34,543	$14,154	$7,583	$506							$66,558
	PM Costs Recovered		$2,384	$2,384	$2,384	$6,596	$8,322	$7,664	$7,726	$7,726	$3,514	$1,788	$62		$50,548
	NOx Costs Recovered					$4,212	$5,938	$6,062	$6,123	$6,123	$1,911	$185	$62		$30,616
	Total Costs Recovered		$2,384	$2,384	$2,384	$10,808	$14,260	$13,726	$13,849	$13,849	$5,425	$1,973	$123		$81,164

6.2.1.3 Engine Certification Costs

Manufacturers will incur more than the normal level of certification costs during the first few years of implementation because engines will need to be certified to the new emission standards. Consistent with our recent standard setting regulations, we have estimated engine certification costs at $60,000 per new engine certification to cover testing and administrative costs.[8] To this we have added the proposed certification fee of $2,156 per new engine family.[9] This cost, $62,156 per engine family was used for <75 horsepower engines certifying to the 2008 standards. For 25 to 75 horsepower engines certifying to the 2013 standards, and for >75 horsepower engines certifying to their proposed standards, we have added costs to cover the proposed test procedures for nonroad diesel engines (i.e., the transient test and the NTE); these costs were estimated at $10,500 per engine family. These certification costs—whether it be the $62,156 or the $72,656 per engine family—apply equally to all engine families for all manufacturers regardless of the markets into which the manufacturer sells.

To determine the number of engine families to be certified, we used our certification database for the 2002 model year. That database provides the number of engine families and the associated horsepower rating of each. We grouped those horsepower ratings into the nine horsepower ranges shown in Table 6.2-7. We have chosen these nine horsepower categories for a couple of reasons: (1) phase-ins of standards and/or different levels of baseline versus proposed standards force such breakouts; and, (2) greater stratification (i.e., breaking up the 75 to 175 horsepower range and the 175 to 750 horsepower range) provides a better picture of cost recovery because it more accurately matches the number of engine families (certification costs) with the level of engine sales (cost recovery). Some engine families will undergo more than one certification process due to the structure of the proposed engine standards. Table 6.2-7 shows the number of engine families in each horsepower range and the year for which they would have to be certified to new standards, along with the total certification expenditures for those standards.

The cost expenditures shown in Table 6.2-7 would be incurred one year prior to the years shown in the table. The years shown in the table coincide with the years for which the new standards begin thereby forcing the certification of engines. Half of the 175 to 750 horsepower engine families certified for 2011 must again be certified in 2014 when the NOx phase-in becomes 100 percent. Half of the >750 horsepower engine families get certified in 2011 and the remaining half get certified in 2014 due to the 50/50/50/100 percent PM & NOx phase-ins. For the 25 to 50 horsepower engine families in 2013, half of the certification costs are attributed to PM while half are attributed to NOx due to the proposal to add new PM and NOx standards for those engines in that year; all of the certification costs for 50 to 75 horsepower engine families are attributed to PM because only a new PM standard would be implemented in that year for those engines.

Note that these certification costs should be considered conservative because they assume all engines are certified because of the proposed standards. In reality, some engines would have been certified due to factors independent of the proposed standards. Such engines would have incurred certification costs regardless of any new standards.

Table 6.2-7
Number of Engine Families, Estimated Certification Costs in $2001,
and Allocation of Certification Costs

Horsepower Range	For Proposed Emissions Standards Starting in the Year							
	2008	2011	2012	2013		2014		
0<hp<25	102							
25≤hp<50	132			132				
50≤hp<75	88				88			
75≤hp<100			55					28
100≤hp<175			73					37
175≤hp<300		102				51		
300≤hp<600		64				32		
600≤hp≤750		9				5		
hp>750[a]		20					20	
Total families	322	195	128	132	88	88	20	64
Total Cert Costs ($MM)	$20.0	$14.2	$9.3	$9.6	$6.4	$6.4	$1.5	$4.7
% Allocated to PM	100%	50%	50%	50%	100%	0%	50%	0%
% Allocated to NOx	0%	50%	50%	50%	0%	100%	50%	100%

[a] Forty engine families were certified in the >750 hp range, but only half would be certified in the indicated years due to the proposed phase-in schedule.

To estimate recovery of certification expenditures, we have attributed the expenditures to engines sold in the specific horsepower range and spread the recovery of costs over U.S. sales within that category. Expenditures are incurred one year prior to the emission standard for which the certification is conducted, and are then recovered over a five year period following the certification. A seven percent interest rate is used to account for the time value of money. We have spread these certification costs over only the U.S.-sold engines because the certification conducted for the U.S. is not presumed to fulfill the certification requirements of other countries. Total certification expenditures were estimated at $72 million. Recovery of certification costs was estimated at $88 million. All estimated certification expenditures and the recovery of those expenditures are shown in Table 6.2-8.

Table 6.2-8

Estimated Certification Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2001

Thousands of dollars, except per engine values

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
0<hp<25	Estimated US Sales	147,971	152,087	156,203	160,319	164,435	168,551	172,667	176,783	180,899	185,015	189,131	193,247	193,247	
	PM Costs Incurred	$6,340													$6,340
	NOx Costs Incurred														$0
	PM Costs Recovered		$1,546	$1,546	$1,546	$1,546	$1,546								$7,731
	NOx Costs Recovered														$0
	Per Engine Cost		$10	$10	$10	$9	$9								
25<=hp<50	Estimated US Sales	157,516	161,021	164,526	168,031	171,536	175,041	178,546	182,051	185,556	189,061	192,566	196,071	196,071	
	PM Costs Incurred	$8,205					$4,795								$13,000
	NOx Costs Incurred						$4,795								$4,795
	PM Costs Recovered		$2,001	$2,001	$2,001	$2,001	$2,001	$1,170	$1,170	$1,170	$1,170	$1,170			$15,853
	NOx Costs Recovered							$1,170	$1,170	$1,170	$1,170	$1,170			$5,848
	Per Engine Cost		$12	$12	$12	$12	$11	$13	$13	$13	$12	$12			
50<=hp<75	Estimated US Sales	108,234	110,279	112,325	114,371	116,416	118,462	120,507	122,553	124,599	126,644	128,690	130,736	130,736	
	PM Costs Incurred	$5,470					$6,394								$11,863
	NOx Costs Incurred														$0
	PM Costs Recovered		$1,334	$1,334	$1,334	$1,334	$1,334	$1,559	$1,559	$1,559	$1,559	$1,559			$14,467
	NOx Costs Recovered														$0
	Per Engine Cost		$12	$12	$12	$11	$11	$13	$13	$13	$12	$12			
75<=hp<100	Estimated US Sales	79,159	80,659	82,158	83,657	85,157	86,656	88,155	89,654	91,154	92,653	94,152	95,652	95,652	
	PM Costs Incurred					$1,998									$1,998
	NOx Costs Incurred					$1,998		$1,998							$3,996
	PM Costs Recovered						$487	$487	$487	$487	$487				$2,437
	NOx Costs Recovered						$487	$487	$975	$975	$975	$487	$487		$4,873
	Per Engine Cost						$11	$11	$16	$16	$16	$5	$5		
100<=hp<175	Estimated US Sales	128,588	130,909	133,230	135,551	137,872	140,193	142,514	144,836	147,157	149,478	151,799	154,120	154,120	
	PM Costs Incurred					$2,652									$2,652
	NOx Costs Incurred					$2,652		$2,652							$5,304
	PM Costs Recovered						$647	$647	$647	$647	$647				$3,234
	NOx Costs Recovered						$647	$647	$1,294	$1,294	$1,294	$647	$647		$6,468
	Per Engine Cost						$9	$9	$13	$13	$13	$4	$4		
175<=hp<300	Estimated US Sales	71,749	73,163	74,577	75,991	77,405	78,819	80,233	81,647	83,061	84,475	85,889	87,303	87,303	
	PM Costs Incurred				$3,705										$3,705
	NOx Costs Incurred				$3,705			$3,705							$7,411
	PM Costs Recovered					$904	$904	$904	$904	$904					$4,519
	NOx Costs Recovered					$904	$904	$904	$1,807	$1,807	$904	$904	$904		$9,037
	Per Engine Cost					$23	$23	$23	$33	$33	$11	$11	$10		
300<=hp<600	Estimated US Sales	37,147	37,583	38,019	38,455	38,891	39,327	39,763	40,199	40,635	41,071	41,507	41,943	41,943	
	PM Costs Incurred				$2,325										$2,325
	NOx Costs Incurred				$2,325			$2,325							$4,650
	PM Costs Recovered					$567	$567	$567	$567	$567					$2,835
	NOx Costs Recovered					$567	$567	$567	$1,134	$1,134	$567	$567	$567		$5,670
	Per Engine Cost					$29	$29	$29	$42	$42	$14	$14	$14		
600<=hp<=750	Estimated US Sales	3,102	3,152	3,202	3,252	3,302	3,352	3,402	3,452	3,502	3,552	3,602	3,652	3,652	
	PM Costs Incurred				$327										$327
	NOx Costs Incurred				$327			$327							$654
	PM Costs Recovered					$80	$80	$80	$80	$80					$399
	NOx Costs Recovered					$80	$80	$80	$159	$159	$80	$80	$80		$797
	Per Engine Cost					$48	$48	$47	$69	$68	$22	$22	$22		
>750hp	Estimated US Sales	3,142	3,193	3,244	3,295	3,346	3,397	3,448	3,499	3,550	3,601	3,652	3,703	3,703	
	PM Costs Incurred				$727			$727							$1,453
	NOx Costs Incurred				$727			$727							$1,453
	PM Costs Recovered					$177	$177	$177	$354	$354	$177	$177	$177		$1,772
	NOx Costs Recovered					$177	$177	$177	$354	$354	$177	$177	$177		$1,772
	Per Engine Cost					$106	$104	$103	$203	$200	$98	$97	$96		
All hp	PM Costs Incurred	$20,014			$7,084	$4,650	$11,189	$727							$43,664
	NOx Costs Incurred				$7,084	$4,650	$4,795	$11,734							$28,263
	Total Costs Incurred	$20,014			$14,168	$9,300	$15,984	$12,461							$71,927
	PM Costs Recovered		$4,881	$4,881	$4,881	$6,609	$7,743	$5,591	$5,768	$5,768	$4,040	$2,906	$177		$53,246
	NOx Costs Recovered					$1,728	$2,862	$4,031	$6,893	$6,893	$5,165	$4,031	$2,862		$34,466
	Total Costs Recovered		$4,881	$4,881	$4,881	$8,337	$10,605	$9,622	$12,661	$12,661	$9,206	$6,937	$3,039		$87,712

6.2.2 Engine Variable Costs

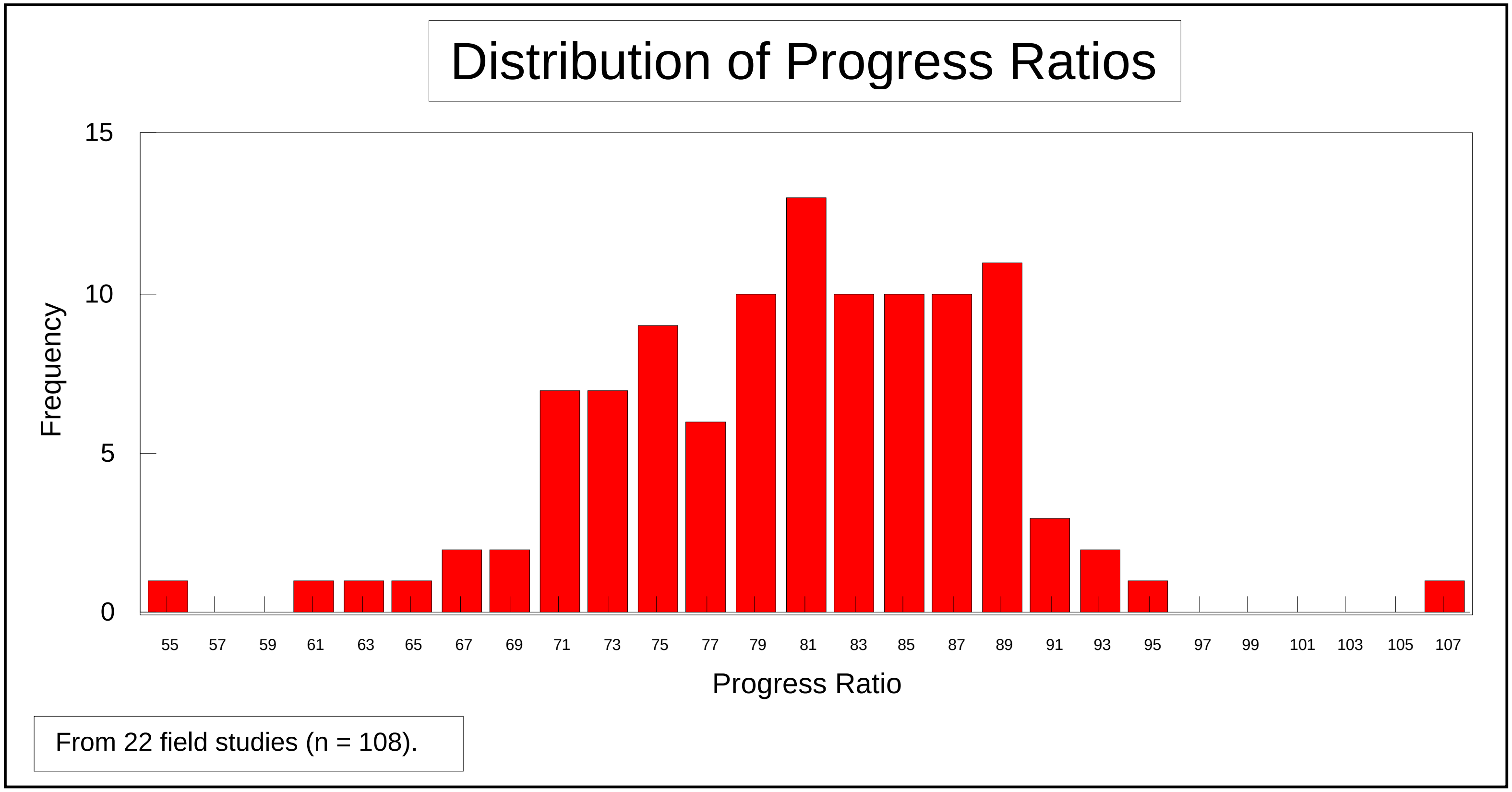
Engine variable costs are those costs for new hardware required to meet the proposed standards. In this section, we present our estimates of engine variable costs. Because of the wide variation of engine sizes in the nonroad market, we have chosen an approach that results not in a specific cost per engine for engines within a given horsepower range, but rather a set of equations that can be used to determine the variable costs for any engine provided its displacement and number of cylinders are known. As a result, we do not present here a cost of say, $50 per engine for engines in the 25 to 50 horsepower range, but instead present cost equations that can be used to determine the variable costs for an engine having, for example, a 0.5 liter engine with two cylinders. We believe this is a more comprehensive approach because it allows the reader to calculate costs more precisely for whatever engine(s) they are interested in. Further, variable costs can vary quite significantly within a given horsepower range unless the range is kept very small. To state an average variable cost for a range such as 175 to 300 horsepower is far less precise than what we present here. Using the equations presented here, we have estimated the engine variable costs for some specific example pieces of equipment; these estimates can be found in Section 6.5 of this Draft RIA.

The discussion here contains both near term and long term cost estimates. We believe there are factors that would cause variable hardware costs to decrease over time, making it appropriate to distinguish between near term and long term costs. Research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts, all of which allows them to lower the per-unit cost of production. These effects are often described as the manufacturing learning curve.[10]

The learning curve is a well documented phenomenon dating back to the 1930s. The general concept is that unit costs decrease as cumulative production increases. Learning curves are often characterized in terms of a progress ratio, where each doubling of cumulative production leads to a reduction in unit cost to a percentage "p" of its former value (referred to as a "p cycle"). The organizational learning which brings about a reduction in total cost is caused by improvements in several areas. Areas involving direct labor and material are usually the source of the greatest savings. Examples include, but are not limited to, a reduction in the number or complexity of component parts, improved component production, improved assembly speed and processes, reduced error rates, and improved manufacturing process. These all result in higher overall production, less scrappage of materials and products, and better overall quality. As each successive p cycle takes longer to complete, production proficiency generally reaches a relatively stable plateau, beyond which increased production does not necessarily lead to markedly decreased costs.

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[11] The distribution of these progress ratios is shown in Figure 6.2-1. Except for one company that saw *increasing* costs as production continued, every study showed cost savings of at least five percent for every doubling of production volume. The average progress ratio for the whole data set falls between 81 and 82 percent. Other studies (Alchian 1963, Argote and Epple 1990, Benkard 1999) appear to support the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

Figure 6.2-1
Distribution of Progress Ratios



Source: Dutton and Thomas, 1984.

The learning curve is not the same in all industries. For example, the effect of the learning curve seems to be less in the chemical industry and the nuclear power industry where a doubling of cumulative output is associated with 11% decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

EPA believes the use of the learning curve is appropriate to consider in assessing the cost impact of diesel engine emission controls. The learning curve applies to new technology, new manufacturing operations, new parts, and new assembly operations. Nonroad diesel engines currently do not use any form of NOx aftertreatment and have used diesel particulate filters in only limited application. Therefore, these are new technologies for nonroad diesel engines and will involve some new manufacturing operations, new parts, and new assembly operations beyond those anticipated in response to the HD2007 rule. Since this will be a new product, EPA believes this is an appropriate situation for the learning curve concept to apply. Opportunities to reduce unit labor and material costs and increase productivity (as discussed above) will be great. EPA believes a similar opportunity exists for the new control systems which will integrate the function of the engine and the emission control technologies. While all nonroad diesel engines beginning with Tier 3 compliance are expected to have the basic components of this system – advanced engine control modules (computers), advanced engine air management systems (cooled EGR, and variable geometry turbocharging), and advanced fuel systems including common rail systems – they will be applied in some new ways in response to the proposed Tier 4 standards. Additionally some new components will be applied for the first time. These new parts and new assemblies will involve new manufacturing operations. As manufacturers gain experience with these new systems, comparable learning is expected to occur with respect to unit labor and material costs. These changes require manufacturers to start new production procedures, which, over time, will improve with experience.

We have applied a p value of 80 percent beginning with the first year of introduction of any new technology. That is, variable costs were reduced by 20 percent for each doubling of cumulative production following the year in which the technology was first introduced in a given horsepower range of engines. This way, learning is applied at the start of 2013 for >175 horsepower engines and in 2014 for 75 to 175 horsepower engines because of the one year difference in their first year of compliance (i.e., the first year in which new technologies are introduced). Because the timing of the proposed standards follows implementation of the HD2007 rule, we have used the first stage of learning done via that rule as the starting point of learning for nonroad engines. In other words, the first learning phase in highway serves as the baseline level of learning for nonroad. We have then applied one additional learning step from there. In the HD2007 rule, we applied a second learning step following the second doubling of production that would occur at the end of the 2010 model year. We could have chosen that point as our baseline case for nonroad and then applied a single learning curve effect from there. Instead, we have chosen to use as our nonroad baseline the first learning step from the highway rule so that, with our single nonroad learning step, we have costs consistent with those costs estimated for highway diesel engines. In the long term, after applying the nonroad learning curve, our cost estimates for CDPFs and NOx adsorbers are the same for similar nonroad and highway diesel engines. This approach is consistent with the approach taken in our Tier 2 light-duty highway rule and the HD2007 rule for heavy-duty gasoline engines. There, compliance was being met through improvements to existing technologies rather than the development of new technologies. We argued in those rules that, with existing technologies, there would be less opportunity for lowering production costs. For that reason, we applied only one learning curve effect. The situation is similar for nonroad engines. Because the technologies will be, by the time they are introduced into the market, existing technologies, there would arguably be less opportunity for learning than there will be for the highway engines where the technologies are first introduced.

Another factor that plays into our near term and long term cost estimates is that for warranty claim rates. In our HD2007 rule, we estimated a warranty claim rate of one percent. Subsequent to that rule, we learned from industry that repair rates can be as much as two to three times higher during the initial years of production for a new technology relative to later years.[12] For this analysis, we have applied what we have learned in our warranty estimates by using a three percent warranty claim rate during the first two years and then one percent warranty claim rate thereafter. This difference in warranty claim rates, in addition to the learning effects discussed above, is reflected in the different long term costs relative to near term costs.

6.2.2.1 NOx Adsorber System Costs

The NOx adsorber system that we are anticipating would be applied for Tier 4 would be the same as that used for highway applications. In order for the NOx adsorber to function properly, a systems approach that includes a reductant metering system and control of engine A/F ratio is also necessary. Many of the new air handling and electronic system technologies developed in order to meet the Tier 2/3 nonroad engine standards can be applied to accomplish the NOx adsorber control functions as well. Some additional hardware for exhaust NOx or O_2 sensing and for fuel metering will likely be required. The cost estimates include a DOC for clean-up of hydrocarbon emissions that occur during NOx adsorber regeneration events.

We have used the same methodology to estimate costs associated with NOx adsorber systems as was used in our 2007 HD Highway rulemaking. The basic components of the NOx adsorber catalyst are well known and include the following material elements:

- an oxidation catalyst, typically platinum based;
- an alkaline earth metal to store NOx, typically barium based;
- a NOx reduction catalyst, typically rhodium based;
- a substrate upon which the catalyst washcoating is applied; and,
- a can to hold and support the substrate.

Examples of these material costs are summarized in Table 6.2-9 and represent costs to the engine manufacturers inclusive of supplier markups. The manufacturer costs shown in Table 6.2-9 (as well as Tables 6.2-11 and 6.2-16 for CDPF systems and DOCs, respectively) include additional markups to account for both manufacturer and dealer overhead and carrying costs. The application of overhead and carrying costs are consistent with the approach taken in the HD2007 rulemaking. In that rule, we used an approach to estimating the markup for catalyzed emission control technologies based on input from catalyst manufacturers. Specifically, we were told that device manufacturers could not markup the cost of the individual components within their products because those components consist of basic commodities (e.g., precious metals used in the catalyst could not be arbitrarily marked up because of their commodity status). Instead, manufacturing entities could only markup costs where they add a unique value to the product. In the case of catalyst systems, we were told that the underlying cost of precious metals, catalyst substrates, PM filter substrates, and canning materials were well known to both buyer and seller and no markup or profit recovery for those component costs could be derived by the catalyst manufacturer. In essence, these are components to which the supplier provides little value added engineering. The one component that was unique to each catalyst manufacturer (i.e., the component where they add a unique value) was the catalyst washcoat support materials. This mixture, of what is essentially specialized clays, serves to hold the catalytic metals in place and to control the surface area of the catalytic metals available for emission control. Although, the commodity price for the materials used in the washcoat is almost negligible (i.e. perhaps one or two dollars), we have estimated a substantial cost for washcoating based on the engineering value added by the catalyst manufacturer in this step. This is reflected in the costs presented for NOx adsorber systems, CDPF systems, and DOCs. This portion of the cost estimate – the washcoating – is where the catalyst manufacturer recovers the fixed cost for research and development as well as realizes a profit. To these manufacturer costs, we have added a four percent carrying costs to account for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. A dealer carrying cost in included to cover the cost of capital tied up in extra inventory. Considering input received from industry, we have adopted this approach of estimating individually the manufacturer and dealer markups in an effort to better reflect the value each entity adds at various stages of the supply chain.[13] Also included is our estimate of warranty costs for the NOx adsorber system.

Table 6.2-9. NOx Adsorber System Costs

	NOx Adsorber Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Engine Displacement (Liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Material and Component Costs								
Catalyst Volume (Liter)	0.59	2.25	5.88	7.05	11.46	27.00	30.45	51.75
Substrate	$3	$13	$33	$39	$64	$151	$170	$290
Washcoating and Canning	$14	$53	$139	$167	$271	$638	$720	$1,223
Platinum	$16	$62	$163	$195	$318	$748	$844	$1,434
Rhodium	$3	$11	$28	$34	$55	$129	$145	$246
Alkaline Earth Oxide, Barium	$1	$1	$1	$1	$1	$1	$1	$1
Catalyst Can Housing	$9	$9	$9	$9	$13	$19	$19	$19
Direct Labor Costs								
Estimated Labor hours	2	2	2	2	2	2	2	2
Labor Rate ($/hr)	$28	$28	$28	$28	$28	$28	$28	$28
Labor Cost	$42	$42	$42	$42	$42	$56	$56	$56
Labor Overhead @ 40%	$17	$17	$17	$17	$17	$22	$22	$22
Total Direct Costs to Mfr.	$105	$208	$432	$504	$780	$1,764	$1,977	$3,291
Warranty Cost -- Near Term (3% claim rate)	$9	$17	$34	$39	$60	$132	$148	$247
Mfr. Carrying Cost -- Near Term	$4	$8	$17	$20	$31	$71	$79	$132
Total Cost to Dealer -- Near Term	$119	$233	$483	$564	$872	$1,967	$2,204	$3,670
Dealer Carrying Cost -- Near Term	$4	$7	$14	$17	$26	$59	$66	$110
DOC for cleanup -- Near Term	$106	$134	$195	$214	$291	$468	$507	$749
Baseline Cost to Buyer -- Near Term	$228	$374	$692	$795	$1,189	$2,494	$2,778	$4,529
Cost to Buyer w/ Highway learning -- Near Term	$204	$326	$593	$679	$1,009	$2,089	$2,323	$3,773
Warranty Cost -- Long Term (1% claim rate)	$3	$6	$11	$13	$20	$44	$49	$82
Mfr. Carrying Cost -- Long Term	$4	$8	$17	$20	$31	$71	$79	$132
Total Cost to Dealer -- Long Term	$113	$222	$460	$537	$832	$1,879	$2,105	$3,505
Dealer Carrying Cost -- Long Term	$3	$7	$14	$16	$25	$56	$63	$105
DOC for cleanup -- Long Term	$100	$127	$185	$204	$277	$446	$483	$715
Baseline Cost to Buyer -- Long Term	$216	$355	$659	$757	$1,134	$2,381	$2,652	$4,325
Cost to Buyer w/ Highway learning -- Long Term	$193	$310	$564	$647	$962	$1,994	$2,218	$3,603
Cost to Buyer w/ Nonroad learning -- Long Term	$174	$273	$489	$558	$825	$1,684	$1,871	$3,026

We have estimated the cost of this system based on information from several reports.[14, 15, 16] The individual estimates and assumptions used to estimate the cost for the system are documented in the following subsections.

NOx Adsorber Catalyst Volume

The Engine Manufacturers Association was asked as part of a contractor work assignment to gather input from their members on likely technology solutions including the NOx adsorber catalyst.[17] The respondents indicated that the catalyst volume for a NOx adsorber catalyst could range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on today's washcoating technology. Based on current lean burn gasoline catalyst designs and engineering judgement, we have estimated that the NOx adsorber catalyst will be sized on average 1.5 times the engine displacement. This is consistent with the size of the NOx adsorber catalyst on the Toyota Avensis diesel passenger car (60 prototypes of a planned 2003 production car are being tested in Europe) which is sized at 1.4 times engine displacement.[18]

NOx Adsorber Substrate

The ceramic flow through substrates used for the NOx adsorber catalyst were estimated to cost $5.27 ($1999) per liter during our 2007 Highway rule. This cost estimate was based upon a relationship developed for current heavy-duty gasoline catalyst substrates.[19] We have converted that value to $5.60 ($2001) using the PPI for Motor Vehicle Parts and Accessories, Catalytic Convertors.[20]

NOx Adsorber Washcoating and Canning

We have estimated a "value-added" engineering and material product, called washcoating and canning, based on feedback from members of the Manufacturers of Emission Control Association (MECA).[21] By using a value added component that accounts for fixed costs (including R&D), overhead, marketing and profits from likely suppliers of the technology, we can estimate this fraction of the cost for the technology apart from the other components which are typically more widely available as commodities (e.g, precious metals and catalyst substrates). Based on conversations with MECA, we understand this element of the product to represent the catalyst manufacturer's value added and, therefore, their opportunity for markup. As a result, the washcoating and canning costs shown in Table 6.2-9 represent costs with manufacturer markups included.

NOx Adsorber Precious Metals

The total precious metal content for the NOx adsorber is estimated to be 50 g/ft^3 with platinum representing 90% of that total and rhodium representing 10%. The costs for rhodium and platinum used in this analysis are the 2002 average prices of $839 per troy ounce for rhodium and $542 per troy ounce for platinum, as reported by Johnson Matthey.[22]

NOx Adsorber Alkaline Earth Metal – Barium

The cost for barium carbonate (the primary NOx storage material) is assumed to be less than $1 per catalyst as estimated in “Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content.”

NOx Adsorber Can Housing

The material cost for the can housing is estimated based on the catalyst volume plus 20% for transition cones, plus 20% for scrappage (material purchased but unused in the final product) and a price of $1.04 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2001.[23]

NOx Adsorber Direct Labor

The direct labor costs for the catalyst are estimated based upon an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[24]

NOx Adsorber Warranty

We have estimated both near term and long term warranty costs. Near term warranty costs are based on a three percent claim rate and an estimate of parts and labor costs per incident, while long term warranty costs are based on a one percent claim rate and an estimate of parts and labor costs per incident. The labor rate is assumed to be $50 per hour with four hours required per claim, and parts costs are estimated to be 2.5 times the original manufacturing cost for the component. The calculation of near term warranty costs for the 9 horsepower engine shown in Table 6.2-9 would be:

$$[(\$3 + \$14 + \$16 + \$3 + \$1 + \$9)(2.5) + (\$50)(4\text{hours})](3\%) = \$9.45$$

NOx Adsorber Manufacturer and Dealer Carrying Costs

The manufacturer’s carrying cost was estimated at 4% of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer’s carrying cost was estimated at 3% of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.[25]

NOx Adsorber DOC for System Clean-up

Included in the costs for the NOx adsorber system are costs for a diesel oxidation catalyst (DOC) for clean-up of possible excess hydrocarbon emissions that might occur as a result of system regeneration (removal of stored NOx and reduction to N_2 and O_2). The methodology used to estimate DOC system costs is consistent with the methodology outlined here for NOx adsorber systems and is presented in Section 6.2.2.3, below. Important to note here is that the DOC costs shown in Table 6.2-9 are lower in the long term because of the lower warranty claim rate – 3 percent in the near term and one percent in the long term; learning effects, as discussed below, are not applied to DOC costs.

NOx Adsorber Cost Estimation Function

Using the example NOx adsorber costs shown in Table 6.2-9, we calculated a linear regression to determine the NOx adsorber system cost as a function of engine displacement. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total or per engine costs for NOx adsorber hardware. The functions calculated for NOx adsorber system costs used throughout this analysis are shown in Table 6.2-10. Note that Table 6.2-9 shows NOx adsorber system costs for engines below 75 horsepower. We do not anticipate any engines below 75 horsepower will apply NOx adsorber systems to comply with the proposed standards. Nonetheless, the costs shown were used to generate the equations shown in Table 6.2-10. Because of the linear relationship between engine displacement and NOx adsorber system size (and, therefore, cost), including the costs for these smaller engines does not inappropriately shift the cost equation downward.

Table 6.2-10
NOx Adsorber System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near Term Cost Function	\$105(x) + \$181	R^2=0.9998
Long Term Cost Function	\$84(x) + \$159	R^2=0.9997

Table 6.2-10 shows both a near term and a long term cost function for NOx adsorber system costs. The near term function incorporates the near term warranty costs determined using a three percent claim rate, while the long term function incorporates the long term warranty costs determined using a one percent claim rate. Additionally, the long term function incorporates learning curve effects for certain elements of the NOx adsorber system (i.e., learning effects were not applied to the DOC portion of the NOx adsorber system, for reasons discussed below). In the HD2007 rule, we applied two learning effects of 20 percent. Here, we have assumed one learning effect of 20 percent as a baseline level of learning; this represents learning done as a result of the HD2007 rule. After a single doubling of production (i.e., two years), we have then applied a single *nonroad* learning effect of 20 percent. Note that the equations shown in Table 6.2-10 include costs for a clean-up DOC; results generated using the DOC cost estimation equations presented in Table 6.2-14 should *not* be added to results generated using the equations in Table 6.2-10 to determine NOx adsorber system costs.

6.2.2.2 Catalyzed Diesel Particulate Filter Costs

As with the NOx adsorber system, the CDPF system that we are anticipating would be applied for Tier 4 would be the same as that used for highway applications, except that we are projecting that some form of active regeneration system would be employed as a backup to the passive regeneration capability of the CDPF. In order for the CDPF to function properly, a systems approach that includes a reductant metering system and control of engine A/F ratio is also necessary. Many of the new air handling and electronic system technologies developed in order to meet the Tier 2/3 nonroad engine standards can be applied to accomplish the CDPF control functions as well. Nonroad applications are expected to present challenges beyond those of highway applications with respect to implementing CDPFs. For this reason, we anticipate that some additional hardware beyond the diesel particulate filter itself may be required to ensure that CDPF regeneration occurs. For some engines this may be new fuel control strategies that force regeneration under some circumstances, while in other engines it might involve an exhaust system fuel injector to inject fuel upstream of the CDPF to provide necessary heat for regeneration under some operating conditions. The cost estimates for such a regeneration system are presented in section 6.2.2.3.

We have used the same methodology to estimate costs associated with CDPF systems as was used in our 2007 HD Highway rulemaking (although here, for nonroad engines, we have included costs for a regeneration system that was not part of the cost estimate in the 2007 HD rule). The basic components of the CDPF are well known and include the following material elements:

- an oxidation catalyst, typically platinum based;
- a substrate upon which the catalyst washcoating is applied and upon which PM is trapped;
- a can to hold and support the substrate; and,
- a regeneration system to ensure regeneration under all operating conditions (see section 6.2.2.3).

Examples of these material costs are summarized in Table 6.2-11 and represent costs to the engine manufacturers inclusive of supplier markups. The total direct cost to the manufacturer includes an estimate of warranty costs for the CDPF system. Hardware costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer's carrying cost was estimated to be four percent of the direct costs accounting for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. The dealer's carrying cost was marked up three percent reflecting the cost of capital tied up in inventory. Considering input received from industry, we have adopted this approach of estimating individually the manufacturer and dealer markups in an effort to better reflect the value added at each stage of the supply chain.[26]

Table 6.2-11. Catalyzed Diesel Particulate Filter (CDPF) System Costs

	Catalyzed Diesel Particulate Filter (CDPF) Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Average Engine Displacement (Liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Material and Component Costs								
Filter Volume (Liter)	0.59	2.25	5.88	7.05	11.46	27.00	30.45	51.75
Filter Trap	$37	$143	$375	$449	$730	$1,721	$1,940	$3,298
Washcoating and Canning	$14	$53	$139	$167	$271	$638	$720	$1,223
Platinum	$11	$42	$109	$130	$212	$499	$563	$956
Filter Can Housing	$7	$7	$7	$7	$11	$15	$15	$15
Differential Pressure Sensor	$48	$48	$48	$48	$48	$48	$96	$96
Direct Labor Costs	$0	$0	$0	$0	$0	$0	$0	$0
Estimated Labor hours	2	2	2	2	2	2	4	4
Labor Rate ($/hr)	$28	$28	$28	$28	$28	$28	$28	$28
Labor Cost	$56	$56	$56	$56	$56	$56	$112	$112
Labor Overhead @ 40%	$22	$22	$22	$22	$22	$22	$45	$45
Total Direct Costs to Mfr.	$195	$372	$756	$880	$1,350	$2,998	$3,490	$5,744
Warranty Cost -- Near Term (3% claim rate)	$12	$25	$54	$63	$98	$222	$253	$422
Mfr. Carrying Cost -- Near Term	$8	$15	$30	$35	$54	$120	$140	$230
Total Cost to Dealer -- Near Term	$215	$411	$840	$978	$1,502	$3,340	$3,882	$6,396
Dealer Carrying Cost -- Near Term	$6	$12	$25	$29	$45	$100	$116	$192
Savings by removing muffler	-$48	-$48	-$48	-$48	-$48	-$48	-$48	-$48
Baseline Cost to Buyer -- Near Term	$174	$376	$817	$959	$1,499	$3,393	$3,951	$6,540
Cost to Buyer w/ Highway learning -- Near Term	$139	$301	$654	$768	$1,199	$2,714	$3,161	$5,232
Warranty Cost -- Long Term (1% claim rate)	$4	$8	$18	$21	$33	$74	$84	$141
Mfr. Carrying Cost -- Long Term	$8	$15	$30	$35	$54	$120	$140	$230
Total Cost to Dealer -- Long Term	$207	$395	$804	$936	$1,436	$3,192	$3,714	$6,114
Dealer Carrying Cost -- Long Term	$6	$12	$24	$28	$43	$96	$111	$183
Savings by removing muffler	-$48	-$48	-$48	-$48	-$48	-$48	-$48	-$48
Baseline Cost to Buyer -- Long Term	$166	$359	$780	$916	$1,432	$3,240	$3,777	$6,250
Cost to Buyer w/ Highway learning -- Long Term	$132	$287	$624	$733	$1,145	$2,592	$3,022	$5,000
Cost to Buyer w/ Nonroad learning -- Long Term	$106	$230	$499	$586	$916	$2,074	$2,417	$4,000

CDPF Volume

During development of our HD2007 rule, the Engine Manufacturers Association was asked as part of a contractor work assignment to gather input from their members on catalyzed diesel particulate filters for heavy-duty highway applications.[27] The respondents indicated that the particulate filter volume could range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on their experiences at that time with cordierite filter technologies. The size of the diesel particulate filter is selected largely based upon the maximum allowable flow restriction for the engine. Generically, the filter size is inversely proportional to its resistance to flow (a larger filter is less restrictive than a similar smaller filter). In the HD2007 rule and here, we have estimated that the diesel particulate filter will be sized to be 1.5 times the engine displacement based on the responses received from EMA and on-going research aimed at improving filter porosity control to give a better trade-off between flow restrictions and filtering efficiency.

CDPF Substrate

In the HD2007 rule, we estimated that CDPFs would consist of a cordierite filter costing $30 per liter. For nonroad applications, we have assumed the use of silicon carbide filters costing double that amount, or $60 per liter. This cost is directly proportional to filter volume, which is proportional to engine displacement. This $60 value is then converted to $2001 using the PPI for Motor Vehicle Parts and Accessories, Catalytic Convertors.[28] The end result being a cost of $64 per liter.

CDPF Washcoating and Canning

These costs were done in a consistent manner as done for NOx adsorber catalyst systems as discussed above.

CDPF Precious Metals

The total precious metal content for catalyzed diesel particulate filters is estimated to be 30 g/ft^3 with platinum as the only precious metal used in the filter. As done for NOx adsorbers, we have used a price of $542 per troy ounce for platinum.

CDPF Can Housing

The material cost for the can housing is estimated based on the CDPF volume plus 20% for transition cones, plus 20% for scrappage (material purchased but unused in the final product) and a price of $1.04 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2001.[29]

CDPF Differential Pressure Sensor

We have assumed that the catalyzed diesel particulate filter system will require the use of a differential pressure sensor to provide a diagnostic monitoring function of the filter. A contractor report to EPA estimated the cost for such a sensor at $45.[30] A PPI adjusted cost of $48 per sensor has been used in this analysis.

CDPF Direct Labor

Consistent with the approach for NOx adsorber systems, the direct labor costs for the CDPF are estimated based upon an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[31]

CDPF Warranty

We have estimated both near term and long term warranty costs. Near term warranty costs are based on a three percent claim rate and an estimate of parts and labor costs per incident, while long term warranty costs are based on a one percent claim rate and an estimate of parts and labor costs per incident. The labor rate is assumed to be $50 per hour with two hours required per claim, and parts cost are estimated to be 2.5 times the original manufacturing cost for the component.

CDPF Manufacturer and Dealer Carrying Costs

Consistent with the approach for NOx adsorber systems, the manufacturer's carrying cost was estimated at 4% of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3% of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.[32]

Savings Associated with Muffler Removal

CDPF retrofits today are often incorporated in, or are simply replacements for, the muffler for diesel powered vehicles and equipment. One report noted that, "Often, the trap could be mounted in place of the muffler and had the same dimensions. Thus, rapid replacement was possible. The muffling effect was often even better."[33] We have assumed that applying a CDPF allows for the removal of the muffler due to the noise attenuation characteristics of the CDPF. We have accounted for this savings and have estimated a muffler cost of $48. The $48 estimate is an average for all engines, the actual savings would be higher for some and lower for others.

CDPF System Cost Estimation Function

Using the example CDPF costs shown in Table 6.2-11, we calculated a linear regression to determine the CDPF system cost as a function of engine displacement. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total or per engine costs for CDPF system hardware. The functions calculated for CDPF system costs used throughout this analysis are shown in Table 6.2-12.

Table 6.2-12
CDPF System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near term Cost Function	\$150(x) + \$71	R^2=0.9998
Long term Cost Function	\$114(x) + \$54	R^2=0.9998

The near term and long term costs shown in Table 6.2-12 change due to the different warranty claim rates and the application of a 20 percent learning curve effect.

6.2.2.3 CDPF Regeneration System Costs

The CDPF regeneration system is likely to include an O_2 sensor, a means for exhaust air to fuel ratio control (one or more exhaust fuel injectors or in-cylinder means), a temperature sensor and possibly a means to control mass flow through a portion of the catalyst system (e.g., for a "dual-bed" system). Incremental costs for a CDPF regeneration system, along with several other costs discussed below, were developed by ICF Consulting under contract to EPA. The results of that cost analysis are detailed in the report entitled, "Electronic Systems and EGR Costs for Nonroad Engines," which is contained in the docket for this rule.[34] The cost estimates developed by ICF for a CDPF regeneration system are summarized in Table 6.2-13.

Using these costs, we then estimated costs to the buyer using the same learning curve effects and warranty claim rate factors discussed above. These results are presented in Table 6.2-14.

Table 6.2-13.
CDPF Regeneration System – Costs to the Manufacturer

ICF Estimated Regeneration System Costs to Manufacturers (\$2001)								
Horsepower	20	35	80	150	250	400	650	1000
Displacement (L)	1	2	3	6	8	10	16	24
CDPF Regeneration System Costs	\$260	\$274	\$287	\$376	\$398	\$420	\$514	\$654

Table 6.2-14.
CDPF Regeneration System – Costs to the User

EPA Estimate of CDPF Regeneration System Costs ($2001)								
Horsepower	20	35	80	150	250	400	650	1000
Displacement (L)	1	2	3	6	8	10	16	24
CDPF Regeneration System Costs	$260	$274	$287	$376	$398	$420	$514	$654
Warranty Cost -- Near Term (3% claim rate)	$23	$24	$25	$31	$33	$34	$42	$52
Mfr. Carrying Cost (4%) -- Near Term	$10	$11	$11	$15	$16	$17	$21	$26
Total Cost to Dealer -- Near Term	$293	$308	$323	$422	$447	$471	$576	$733
Dealer Carrying Cost (3%) -- Near Term	$9	$9	$10	$13	$13	$14	$17	$22
Total Cost to Buyer -- Near Term	$302	$317	$333	$435	$460	$485	$593	$755
Warranty Cost -- Long Term (1% claim rate)	$8	$8	$8	$10	$11	$11	$14	$17
Mfr. Carrying Cost (4%)-- Long Term	$10	$11	$11	$15	$16	$17	$21	$26
Total Cost to Dealer -- Long Term	$278	$292	$307	$401	$425	$448	$548	$698
Dealer Carrying Cost (3%) -- Long Term	$8	$9	$9	$12	$13	$13	$16	$21
Subtotal	$286	$301	$316	$413	$437	$462	$565	$719
Total Cost to Buyer -- Long-Term w/ learning	$229	$241	$253	$331	$350	$369	$452	$575

As noted above, the CDPF regeneration system is expected to consist of an O_2 sensor, a temperature sensor, and probably a pressure sensor. The costs shown in Table 6.2-14 assume none of these sensors or other pieces of hardware exist and, more importantly, they assume the fuel control systems present in the engine are not capable of the sort of precise fuel control that could perform many of the necessary functions of the regeneration system without any additional hardware. For this reason, we consider the costs shown in Table 6.2-14 to be representative of the costs that would be incurred on an engine with an indirect injection (IDI) fuel system. For a direct injection (DI) fuel system, we expect that many of the functional capabilities for which costs were generated would be handled by the existing fuel system. For example, we are assuming that all DI engines will either convert to a fuel system capable of late injection or will already have a fuel system capable of late injection. Late injection is one of the primary means of using fuel strategies to force a CDPF regeneration event. Our cost estimates associated with conversion to such fuel systems are discussed below. Because the regeneration system costs for DI engines would be lower than those for an IDI engine, we have estimated that the regeneration system costs for a DI engine would be one-half those presented in Table 6.2-14.

Also, note that the air handling, electronic, and fuel system hardware used for backup active CDPF regeneration is expected to be used in common with the NOx adsorber regeneration system. We have accounted for these costs here (as a CDPF regeneration system) because CDPFs are required on a broader range of engines and, for many engines, earlier than are NOx adsorbers.

CDPF Regeneration System Cost Estimation Function

Using the example regeneration system costs shown in Table 6.2-14, we calculated a linear regression to determine the CDPF regeneration system cost as a function of engine displacement. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total costs for CDPF regeneration system hardware. The functions calculated for CDPF regeneration system costs used throughout this analysis are shown in Table 6.2-15.

Table 6.2-15
CDPF Regeneration System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

IDI Engine	Near term Cost Function	\$20(x) + \$289	R^2=0.9912
	Long term Cost Function	\$15(x) + \$219	R^2=0.9912
DI Engine	Near term Cost Function	\$10(x) + \$144	R^2=0.9912
	Long term Cost Function	\$7(x) + \$110	R^2=0.9912

Note that these costs – either the IDI or the DI costs, depending on the type of engine – would be incurred for any engine adding a CDPF. The near term and long term costs shown in Table 6.2-15 change due to the different warranty claim rates and the application of a 20 percent learning curve effect.

6.2.2.4 Diesel Oxidation Catalyst (DOC) Costs

The NOx adsorber regeneration and desulfation functions may produce undesirable by-products in the form of momentary increases in HC emissions or in odorous hydrogen sulfide (H_2S) emissions. In order to control these potential products, we have assumed that manufacturers may choose to apply a diesel oxidation catalyst (DOC) downstream of the NOx adsorber technology. The DOC would serve a “clean-up” function to oxidize any HC and H_2S emissions to more desirable products. As discussed below, for our cost analysis we have also estimated that engines <75 horsepower would add a DOC to comply with the 2008 PM standards, not to serve a “clean-up” function but rather to serve as the primary means of emission control.

Our estimates of DOC costs are shown in Table 6.2-16. The individual component costs for the DOC were estimated in the same manner as for the NOx adsorber systems and CDPF systems, as discussed above. However, no learning effects were applied to DOCs because we believe that DOCs have been manufactured for a long enough time period such that learning has already taken place.

Table 6.2-16.
Diesel Oxidation Catalyst (DOC) Costs

	Diesel Oxidation Catalyst Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Average Engine Displacement (Liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Material and Component Costs								
Catalyst Volume (liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Substrate	$2	$8	$22	$26	$43	$101	$114	$193
Washcoating and Canning	$63	$78	$110	$120	$159	$214	$227	$302
Platinum (5 g/ft3)	$1	$5	$12	$14	$24	$55	$63	$106
Catalyst Can Housing	$5	$5	$5	$5	$7	$16	$18	$30
Direct Labor Costs								
Estimated Labor hours	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Rate ($/hr)	$28	$28	$28	$28	$28	$28	$28	$28
Labor Cost	$14	$14	$14	$14	$14	$14	$14	$14
Labor Overhead @ 40%	$6	$6	$6	$6	$6	$6	$6	$6
Total Direct Costs to Mfr.	$91	$115	$168	$185	$252	$406	$440	$651
Warranty Cost -- Near Term (3% claim rate)	$8	$10	$14	$15	$20	$32	$35	$50
Mfr. Carrying Cost -- Near Term	$4	$5	$7	$7	$10	$16	$18	$26
Total Cost to Dealer -- Near Term	$103	$130	$189	$208	$282	$454	$492	$728
Dealer Carrying Cost -- Near Term	$3	$4	$6	$6	$8	$14	$15	$22
Total Cost to Buyer -- Near Term	$106	$134	$195	$214	$291	$468	$507	$749
Warranty Cost -- Long Term (1% claim rate)	$3	$3	$5	$5	$7	$11	$12	$17
Mfr. Carrying Cost -- Long Term	$4	$5	$7	$7	$10	$16	$18	$26
Total Cost to Dealer -- Long Term	$97	$123	$180	$198	$269	$433	$469	$694
Dealer Carrying Cost -- Long Term	$3	$4	$5	$6	$8	$13	$14	$21
Total Cost to Buyer -- Long Term	$100	$127	$185	$204	$277	$446	$483	$715

DOC Cost Estimation Function

Similar to what was done for NOx adsorber systems and CDPFs, we used the example costs shown in Table 6.2-16 to determine a cost function with engine displacement as the dependent variable. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total or per unit costs for DOC hardware, whether that hardware be a stand alone emission control technology or as part of a NOx adsorber system. The cost functions for DOCs used throughout this analysis are shown in Table 6.2-17. Note that the NOx adsorber cost estimation equations shown in Table 6.2-10 include costs for a clean-up DOC; results generated using the DOC cost estimation equations presented in Table 6.2-17 should *not* be added to results generated using the equations in Table 6.2-10 to determine NOx adsorber system costs.

Table 6.2-17
DOC Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near term Cost Function	\$19(x) + \$117	R^2=0.9943
Long term Cost Function	\$18(x) + \$110	R^2=0.9943

6.2.2.5 Closed-Crankcase Ventilation (CCV) System Costs

Consistent with our HD2007 rule, we are proposing to eliminate the exemption that allows turbo-charged nonroad diesel engines to vent crankcase gases directly to the environment. Such engines are said to have an open crankcase system. We project that this requirement to close the crankcase on turbo charged engines would force manufacturers to rely on engineered closed crankcase ventilation systems that filter oil from the blow-by gases prior to routing them into either the engine intake or the exhaust system upstream of the CDPF. We expect these systems to be the same as those expected for highway engines and have estimated their costs in the same manner as done in our HD2007 rule. The estimated initial costs of these systems are as shown in Table 6.2-18. These costs are incurred only by turbo-charged engines.

Table 6.2-18.
Closed Crankcase Ventilation (CCV) System Costs

	Closed Crankcase Ventilation (CCV) System Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Average Engine Displacement (Liter)	0.39	0.93	3.92	4.7	7.64	18	20.3	34.5
Cost to Manufacturer	$29	$30	$36	$37	$43	$62	$67	$94
Warranty Cost -- Near Term (3% claim rate)	$5	$5	$6	$6	$6	$8	$8	$10
Mfr. Carrying Cost -- Near Term	$1	$1	$1	$1	$2	$2	$3	$4
Total Cost to Dealer -- Near Term	$35	$36	$43	$44	$50	$72	$77	$107
Dealer Carrying Cost -- Near Term	$1	$1	$1	$1	$2	$2	$2	$3
Total Cost to Buyer -- Near Term	$36	$37	$44	$46	$52	$75	$80	$111
Warranty Cost -- Long Term (1% claim rate)	$2	$2	$2	$2	$2	$3	$3	$3
Mfr. Carrying Cost -- Long Term	$1	$1	$1	$1	$2	$2	$3	$4
Total Cost to Dealer -- Long Term	$32	$33	$39	$40	$46	$67	$72	$101
Dealer Carrying Cost -- Long Term	$1	$1	$1	$1	$1	$2	$2	$3
Cost to Buyer w/ Nonroad Learning -- Long Term	$26	$27	$32	$33	$38	$55	$59	$83

CCV Cost Estimation Function

As discussed above, an equation was developed as a function of engine displacement to calculate total or per unit CCV costs. These functions are shown in Table 6.2-19. Note that these costs would be incurred only by turbo-charged engines.

Table 6.2-19
CCV Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near term Cost Function	$2(x) + $35	R^2=1
Long term Cost Function	$2(x) + $25	R^2=1

6.2.2.6 Variable Costs of Conventional Technologies for Engines Below 75 Horsepower and over 750 Horsepower

For the smaller horsepower categories, we have projected a different technology mix to enable compliance due to the different proposed standards. From a cost perspective, we have projected that engines would comply by either adding a DOC or by making some engine modifications resulting in engine-out emission reductions. Presumably, the manufacturer would choose the least costly approach that provided the necessary emission reduction. If engine-out modifications are less costly than a DOC, our estimate here is conservative. If the DOC proves to be less costly, then our estimate is representative of what most manufacturers would do. Therefore, we have assumed that, beginning in 2008, all engines below 75 horsepower add a DOC. Note that this is a conservative estimate in that we have assume this cost for all engines when, as discussed in Chapter 4, some engines <75 horsepower already meet the proposed PM standards. Our cost estimates for DOCs are presented above in Section 6.2.2.4.

As discussed in Chapter 4 of this Draft RIA, we have also projected that some engines in the 25 to 75 horsepower range would have to make changes to their engines to incorporate more conventional engine technology such as electronic common rail fuel injection to meet the demands of the newly added CDPF. These costs were assumed for direct injection (DI) engines. For indirect diesel injection (IDI) engines in this horsepower range, we believe that manufacturers would comply not through a fuel system upgrade to electronic common rail, but through the addition of a CDPF regeneration system to ensure regeneration of the CDPF. The costs for CDPF regeneration systems are discussed above in Section 6.2.2.3.

In the 25 to 50 horsepower range, we believe that all engines would add cooled EGR to meet the NOx standards proposed for that horsepower category. This is also true for engines >750 horsepower (note that engines >750 horsepower are also assumed to add the previously discussed exhaust emission control technologies – i.e., a NOx adsorber system, a CDPF system, and some sort of CDPF regeneration system).

All of these engines – those <75 horsepower and those >750 horsepower – are assumed to add CCV systems where those engines are turbocharged. The costs for CCV systems were presented in Section 6.2.2.5 above.

6.2.2.6.1 Electronic Common Rail Fuel Injection System Costs for DI Engines

Cost estimates for fuel injection systems were developed by ICF Consulting under contract to EPA. The results of cost analysis are detailed in the report entitled, "Electronic Systems and EGR Costs for Nonroad Engines," which is contained in the docket for this rule.[35] Table 6.2-20 presents the costs to manufacturers as estimated by ICF for fuel injection systems.

Table 6.2-20
Fuel Injection System – Costs to Manufacturers

	Fuel System Costs ($2001)					
	Baseline System			New System		
Horsepower	20 hp	35 hp	80 hp	20 hp	35 hp	80 hp
Displacement (L)	1	2	3	1	2	3
# of Cylinders/Injectors	2	3	4	2	3	4
Type of Fuel System	Mech	Mech	ER	ECR	ECR	ECR
High Pressure Fuel Pump	$340	$340	$350	$340	$340	$350
Fuel Injectors (each)	$16	$16	$25	$80	$80	$80
Cost for Injectors (total)	$32	$48	$100	$160	$240	$320
Fuel Rail				$100	$100	$100
Computer			$300	$280	$280	$280
Sensors, Wiring, Bearings, etc.	$68	$82	$189	$231	$625	$639
Total Fuel System Cost	$440	$470	$939	$1,111	$1,205	$1,309
Incremental Cost				$671	$735	$370

Mech=Mechanical Fuel Injection; ER=Electronic Rotary Injection; ECR=Electronic Common Rail Injection

Note that engines in the 50 to 75 horsepower range (represented in Table 6.2-20 by the 80 horsepower engine) are assumed to have electronic rotary fuel injection systems as a baseline configuration while smaller engines are assumed to have mechanical fuel injection. On an incremental basis, the costs for common rail fuel injection are much lower when working from an electronic rotary baseline because the electronic fuel pump and the computer are already part of the system. This is the reason for the large difference in fuel system costs for the 80 horsepower engine relative to the 20 and 35 horsepower engines.

The costs shown in Table 6.2-20 show consistency for all elements across the horsepower range. This is because most of the cost elements – fuel pump, costs per injector, and a computer – have little to no relation to engine size or engine displacement. The primary cost element that changes for each of the example engines shown is that for the total cost of injectors. For this reason, the costs can be more easily understood by separating the per injector cost out from the rest of the system. This was done for the costs shown in Table 6.2-21, which also builds on the manufacturer costs shown in Table 6.2-21 to generate costs to the user in the same manner as done for other hardware system costs, as discussed above. We have broken out the fuel system costs in this manner so that a cost equation could be generated that would apply to all engines. Unlike the other cost equations we have generated, the cost equation for fuel systems uses the number of injectors (i.e., the number of cylinders) as the dependent variable rather than using engine displacement. This equation is presented below in Section 6.2.2.6.3.

Table 6.2-21
Incremental Fuel System Costs – Costs to the User

EPA Estimated Incremental Fuel System Costs for DI Engines ($2001)						
Horsepower	20		35		80	
Number of Cylinders (# of injectors)	2		3		4	
	per Injector	Remaining System	per Injector	Remaining System	per Injector	Remaining System
Cost to Manufacturer	$64	$543	$64	$543	$55	$150
Warranty Cost -- Near Term (3% claim rate)	$8	$44	$8	$44	$7	$14
Mfr. Carrying Cost (4%) -- Near Term	$3	$22	$3	$22	$2	$6
Total Cost to Dealer -- Near Term	$74	$608	$74	$608	$64	$170
Dealer Carrying Cost (3%) -- Near Term	$2	$18	$2	$18	$2	$5
Total Cost to Buyer -- Near Term	$77	$627	$77	$627	$66	$175
Warranty Cost -- Long Term (1% claim rate)	$3	$15	$3	$15	$2	$5
Mfr. Carrying Cost (4%)-- Long Term	$3	$22	$3	$22	$2	$6
Total Cost to Dealer -- Long Term	$69	$579	$69	$579	$60	$161
Dealer Carrying Cost (3%) -- Long Term	$2	$17	$2	$17	$2	$5
Subtotal	$71	$597	$71	$597	$61	$166
Total Cost to Buyer -- Long-Term w/ learning	$57	$477	$57	$477	$49	$132

Remaining System includes the fuel pump, fuel rail, computer, wiring, and necessary sensors.

Note that these costs are projected to be incurred only on 25 to 75 horsepower DI engines. Note also that, in determining aggregate variable costs for fuel injection systems, we have attributed half of the costs to the proposed Tier 4 standards. We have done this for two reasons: penetration of electronic fuel systems into the market, and user benefits associated with the new fuel systems. First, we are projecting that by 2008 some engines in the 25-75 hp range will already be equipped with electronic fuel systems independent of the standards contained in this Tier 4 proposal. This is due to the natural progression of electronic fuel systems currently available in larger power engines into some of the smaller power engines. During our discussions with some engine companies, they have indicated that the electronic fuel system technologies they intend to use to comply with the existing Tier 3 standards in the 50-100 hp range. These manufacturers have informed us that these electronic fuel systems will also be sold on engines in the 25-50 hp range for those engine product lines which are built on a common platform as engines above 50 hp. In addition, there are a number of end-user benefits associated with electronic fuel systems. These include better torque response, lower noise, easier servicing via on-board diagnostics, and better engine starting ability. Because we are not able to predict the precise level of penetration of electronic fuel systems, nor are we able to quantify the monetary value of the end-user benefits, we have accounted for these two effects by attributing half of the costs of the electronic fuel systems to the Tier 4 standards.

6.2.2.6.2 Cooled EGR System Costs

Cost estimates for cooled EGR systems were developed by ICF Consulting under contract to EPA. The results of cost analysis are detailed in the report entitled, "Electronic Systems and EGR Costs for Nonroad Engines," which is contained in the docket for this rule.[36] The incremental manufacturer costs for cooled EGR systems are shown in Table 6.2-22.

Table 6.2-22
Cooled EGR System – Costs to Manufacturers

ICF Estimated Cooled EGR System Costs to Manufacturers ($2001)			
Horsepower	20	35	1000
Displacement (L)	1	2	24
EGR Cooler	$36	$63	$289
EGR Bypass	$15	$16	$30
Electronic EGR Valve	$14	$15	$88
EGR Total Cost to Manufacturer	$65	$94	$407

Building on these manufacturer costs, we estimated the costs to the user assuming the warranty claim rates and learning effects already discussed. These results are shown in Table 6.2-23.

Table 6.2-23
Cooled EGR System – Costs to the User

EPA Estimated Cooled EGR Costs ($2001)			
Horsepower	20	35	1000
Displacement (L)	1	2	24
Cost to Manufacturer	$65	$94	$407
Warranty Cost -- Near Term (3% claim rate)	$8	$10	$34
Mfr. Carrying Cost (4%) -- Near Term	$3	$4	$16
Total Cost to Dealer -- Near Term	$75	$108	$457
Dealer Carrying Cost (3%) -- Near Term	$2	$3	$14
Total Cost to Buyer -- Near Term	$78	$111	$471
Warranty Cost -- Long Term (1% claim rate)	$3	$3	$11
Mfr. Carrying Cost (4%)-- Long Term	$3	$4	$16
Total Cost to Dealer -- Long Term	$70	$101	$434
Dealer Carrying Cost (3%) -- Long Term	$2	$3	$13
Subtotal	$72	$104	$447
Total Cost to Buyer -- Long-Term w/ learning	$58	$83	$358

Note that we are projecting that only engines in the 25 to 50 horsepower range (in 2013) and engines >750 horsepower will need to add cooled EGR (consistent with the NOx phase-in from 2011 to 2014) to comply with the proposed standards. All of the costs associated with these systems have been attributed to compliance with the proposed standards (i.e., we have not attributed any costs to user benefits).

6.2.2.6.3 Conventional Technology Cost Estimation Functions

In the same manner as already described for exhaust emission control devices, we were able to calculate cost equations for cooled EGR systems. For fuel systems, rather than a linear regression, we simply expressed the fuel system costs as a function of the number of fuel injectors, and then added on the costs associated with the rest of the system. The rest of the system includes the fuel pump, the computer, wiring and sensors, which should not change relative to engine size or displacement. This way, the functions could be applied to the wide array of engines in the nonroad fleet to determine the total costs or per unit costs for this hardware. The cost estimation functions for these technologies are shown in Table 6.2-24.

Table 6.2-24
Costs for Conventional Technologies as a
Function of the Indicated Parameter (x represents the dependent variable)

Technology	Applicable Hp Range	Dependent Variable	Equation	R^2
Fuel System Costs – DI Only				
Near Term	25<=hp<50	# of cylinders	$77(x) + $627	—[a]
Long Term	25<=hp<50		$57(x) + $477	
Near Term	50<=hp<75		$66(x) + $175	—[a]
Long Term	50<=hp<75		$49(x) + $132	
Cooled EGR System				
Near Term	25<=hp<50; >750hp	displacement	$17(x) + $69	0.9986
Long Term	25<=hp<50; >750hp		$13(x) + $51	0.9986

[a] Not applicable, because a linear regression was not used.

6.2.3 Engine Operating Costs

We are projecting that a variety of new technologies will be introduced to enable nonroad engines to meet the proposed Tier 4 emissions standards. Primary among these are advanced emission control technologies and low-sulfur diesel fuel. The technology enabling benefits of low-sulfur diesel fuel are described in Chapter 4 of this Draft RIA. The incremental cost for low-sulfur fuel is described in Chapter 7 of this Draft RIA and is not presented here. The new emission control technologies are themselves expected to introduce additional operating costs in the form of increased fuel consumption and increased maintenance demands. Operating costs are estimated over the life of the engine and are expressed in terms of cents/gallon of fuel consumed. In Section 6.5 of this Draft RIA, we present these lifetime operating costs as a net present value (NPV) in 2001 dollars for several example pieces of equipment.

A note of clarification should be made here. In Chapter 8 of this Draft RIA, we present aggregate operating costs. Every effort is made to be clear what costs are related to increased costs for low sulfur fuel and what costs are related to maintenance costs and/or savings. The operating costs discussed in this section are only the latter of these – maintenance related costs and/or savings. Increased costs associated with the lowering of sulfur in nonroad diesel fuel are discussed in detail in Chapter 7 of this Draft RIA. The cent per gallon costs presented in Chapter 7, along with the cent per gallon costs and savings present here, are then combined with projected fuel volumes to generate the aggregate costs of our proposed fuel program.

Total operating costs, other than fuel, include the following elements: the change in maintenance costs associated with applying new emission controls to the engines; the change in maintenance costs associated with low sulfur fuel such as extended oil change intervals; the change in fuel costs associated with the incrementally higher costs for low sulfur fuel, and the change in fuel costs due to any fuel consumption impacts associated with applying new emission controls to the engines. This latter cost is attributed to the CDPF and its need for periodic regeneration which we estimate may result in a small fuel consumption increase as discussed in more detail below. Maintenance costs associated with the new emission controls on the engines are expected to increase since these devices represent new hardware and therefore new maintenance demands. Offsetting this cost increase will be a cost savings due to an expected increase in oil change intervals because low sulfur fuel would be far less corrosive than is current nonroad diesel fuel. Less corrosion would mean a slower acidification rate (i.e., less degradation) of the engine lubricating oil and, therefore, more operating hours between needed oil changes.

6.2.3.1 Operating Costs Associated with Oil Change Maintenance for New and Existing Engines

We estimate that reducing fuel sulfur to 500 ppm would reduce engine wear and oil degradation to the existing nonroad diesel fleet as well as locomotive and marine engines, and that a further reduction to 15 ppm sulfur would result in even greater reductions to the nonroad fleet. This reduction in wear and oil degradation would provide a savings to users of this equipment. The cost savings would also be realized by the owners of future nonroad engines that are subject to the standards in today’s proposal. As discussed below, these maintenance savings have been estimated to be greater than 3 cents per gallon for the use of 15 ppm sulfur fuel when compared to the use of today’s unregulated nonroad diesel fuel.

We have identified a variety of benefits from the low-sulfur diesel fuel. These benefits are summarized in Table 6.2-25.

Table 6.2-25.
Engine Components Potentially Affected by Lower Sulfur Levels in Diesel Fuel

Affected Components	Effect of Lower Sulfur	Potential Impact on Engine System
Piston Rings	Reduced corrosion wear	Extended engine life and less frequent rebuilds
Cylinder Liners	Reduced corrosion wear	Extended engine life and less frequent rebuilds
Oil Quality	Reduced deposits, reduced acid build-up, and less need for alkaline additives	Reduce wear on piston ring and cylinder liner and less frequent oil changes
Exhaust System (tailpipe)	Reduced corrosion wear	Less frequent part replacement
Exhaust Gas Recirculation System	Reduced corrosion wear	Less frequent part replacement

The monetary value of these benefits over the life of the equipment will depend upon the length of time that the equipment operates on low-sulfur diesel fuel and the degree to which engine and equipment manufacturers specify new maintenance practices and the degree to which equipment operators change engine maintenance patterns to take advantage of these benefits. For equipment near the end of its life in the 2008 time frame, the benefits will be quite small. However, for equipment produced in the years immediately preceding the introduction of 500 ppm sulfur fuel, the savings would be substantial. Additional savings would be realized in 2010 when the 15 ppm sulfur fuel would be introduced

We estimate the single largest savings would be the impact of lower sulfur fuel on oil change intervals. We have estimated the oil change interval extension that would be realized by the introduction of 500 ppm sulfur fuel in 2007, as well as the additional oil extension that would be realized with the introduction of 15 ppm sulfur nonroad diesel fuel in 2010. These estimates are based on our analysis of publically available information from nonroad engine manufacturers. Due to the wide range of diesel fuel sulfur which today's nonroad engines may see around the world, engine manufacturers specify different oil change intervals as a function of diesel sulfur levels. We have used these data as the basis for our analysis. Taken together, when compared to today's relatively high nonroad diesel fuel sulfur levels, we estimate the use of 500 ppm sulfur fuel would enable an oil change interval extension of 31 percent, while 15 ppm sulfur fuel would enable an oil change interval extension of 35 percent relative to today's products.[37]

We present here a fuel cost savings attributed to the oil change interval extension in terms of a cents per gallon operating cost. We estimate that an oil change interval extension of 31 percent, as would be enabled by the use of 500 ppm sulfur fuel in 2007, results in a weighted fuel operating costs savings of 3.0 cents per gallon for the nonroad fleet. We project an additional weighted cost savings of 0.3 cents per gallon for the oil change interval extension which would be enabled by the use of 15 ppm sulfur beginning in 2010. Thus, for the nonroad fleet as a whole, beginning in 2010, nonroad equipment users can realize an operating cost savings of 3.3

cents per gallon compared to today’s engine. For a typical 100 horsepower nonroad engine, this represents a net present value lifetime savings of more than $500. Table 6.2-26 shows the calculation of cent per gallon savings for various horsepower segments of the nonroad fleet.

Table 6.2-26. Oil Change Maintenance Savings for Existing and New Nonroad, Locomotive, and Marine Engines ($2001)

Oil Change Savings due to Low S	Units	Nonroad Engines									
Rated Power	hp	0-25	25-50	50-75	75-175	175-300	300-600	600-750	750+	Locomotive	Marine
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.38996	0.367	0.367	0.367	0.367	0.367	0.367
Fuel Density	lbm/gallon	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Population Weighted Avg. Horsepower	hp	18	37	67	113	223	381	717	1263	1263	1263
Population Weighted Avg. Activity	hrs/year	524	579	707	696	525	585	931	921	921	921
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.44	0.47	0.56	0.56	0.55	0.54	0.54	0.54
Sump Oil Capacity	L	1.75	3.59	6.50	10.96	21.63	36.96	69.55	122.51	122.51	122.51
Base Oil Change Interval -- 3000 ppm S	hrs	250	250	250	250	250	250	250	250	250	250
Control Oil Change Interval -- 500 ppm S	hrs	327.5	327.5	327.5	327.5	327.5	327.5	327.5	327.5	327.5	327.5
Labor Cost Per Oil Change	$	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$100.00	$100.00	$100.00
Cost of Oil Per Oil Change	$	$3.49	$7.18	$13.00	$21.92	$43.26	$73.91	$139.10	$245.02	$245.02	$245.02
Cost of Oil Filter Per Oil Change		$18.00	$18.00	$18.00	$18.00	$35.00	$35.00	$35.00	$70.00	$70.00	$70.00
Total Cost Per Oil Change	$	$71.49	$75.18	$81.00	$89.92	$128.26	$158.91	$224.10	$415.02	$415.02	$415.02
Fuel Consumption in 3000 ppm Oil Interval	gallons	106	234	424	729	1614	2757	5096	8813	8813	8813
Fuel Consumption in 500 ppm Oil Interval	gallons	139	306	555	955	2114	3612	6676	11546	11546	11546
Oil Change Cost/Gallon fuel in 3000 ppm Interval	$/gallon	$0.67	$0.32	$0.19	$0.12	$0.08	$0.06	$0.04	$0.05	$0.05	$0.05
Oil Change Cost/Gallon fuel 500 ppm Interval	$/gallon	$0.51	$0.25	$0.15	$0.09	$0.06	$0.04	$0.03	$0.04	$0.04	$0.04
Cost Differential -- 3000 to 500 ppm S	$/gallon	$0.160	$0.076	$0.045	$0.029	$0.019	$0.014	$0.010	$0.011	$0.011	$0.011
Control Oil Change Interval -- 15 ppm S	hrs	337.5	337.5	337.5	337.5	337.5	337.5	337.5	337.5	337.5	337.5
Labor Cost Per Oil Change	$	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$100.00	$100.00	$100.00
Cost of Oil Per Oil Change	$	$3.49	$7.18	$13.00	$21.92	$43.26	$73.91	$139.10	$245.02	$245.02	$245.02
Cost of Oil Filter Per Oil Change		$18.00	$18.00	$18.00	$18.00	$35.00	$35.00	$35.00	$70.00	$70.00	$70.00
Total Cost Per Oil Change	$	$71.49	$75.18	$81.00	$89.92	$128.26	$158.91	$224.10	$415.02	$415.02	$415.02
Fuel Consumption in 500 ppm Oil Interval	gallons	139	306	555	955	2114	3612	6676	11546	11546	11546
Fuel Consumption in 15 ppm Oil Interval	gallons	143	316	572	984	2179	3722	6880	11898	11898	11898
Oil Change Cost/Gallon fuel in 500 ppm Interval	$/gallon	$0.51	$0.25	$0.15	$0.09	$0.06	$0.04	$0.03	$0.04	$0.04	$0.04
Oil Change Cost/Gallon fuel in 15 ppm Interval	$/gallon	$0.50	$0.24	$0.14	$0.09	$0.06	$0.04	$0.03	$0.03	$0.03	$0.03
Cost Differential -- 500 to 15 ppm S	$/gallon	$0.015	$0.007	$0.004	$0.003	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
Cost Differential -- 3000 to 15 ppm S	$/gallon	$0.175	$0.083	$0.050	$0.032	$0.021	$0.015	$0.011	$0.012	$0.012	$0.012
Fuel Use Weightings	% total	2.4%	5.1%	14.0%	26.3%	23.0%	17.7%	4.1%	7.5%		

Notes to table 6.2-26:

(1) Oil change intervals are from William Charmley memo to docket.[38]

(2) Labor costs are from ICF Consulting under contract to EPA.[39]

(3) Oil use estimates are based on sump volumes scaled to engine displacement and, as such, they show differences for each horsepower category. The labor and filter costs are average costs across a broad range of horsepower sizes and, as such, may overstate the cost for some engines while understating the costs for others.

Table 6.2-26 shows oil change maintenance intervals for both the 500 ppm fuel and the 15 ppm fuel. The existing and new nonroad fleets would realize the savings associated with the 500 ppm fuel for the years 2007 through 2010, and the the savings associated with the 15 ppm fuel program for the years 2010 and beyond. The locomotive and marine fleet would realize the savings associated with the 500 ppm fuel for the years 2007 and beyond. The oil change maintenance savings for locomotive and marine engines associated with the 15 ppm fuel are shown in Table 6.2-26 for informational purposes only; these values are used only in our analysis of alternative program options presented in Chapter 12 of this Draft RIA. Note that the weighted values of 3.0 cents per gallon and 3.3 cents per gallon are calculated by weighting the cent per gallon for each horsepower category by the fuel use weighting shown in the table.

The savings shown in Table 6.2-26 would occur without additional new cost to the equipment owner beyond the incremental cost of the low-sulfur diesel fuel, although these savings are dependent on changes to existing maintenance schedules. Such changes seem likely given the magnitude of the savings. We have not estimated the value of the savings from the other benefits listed in Table 6.2-25 and, therefore, we believe the 3.3 cents per gallon savings is conservative as it only accounts for the impact of low sulfur fuel on oil change intervals.

Operating costs associated with oil change maintenance are attributed evenly between NOx and PM control.

6.2.3.2 Operating Costs Associated with CDPF Maintenance for New CDPF-Equipped Engines

The maintenance demands associated with the addition of new CDPF hardware were discussed in Chapter 4.1.1.3.4. To be conservative, we have used a maintenance interval of 3,000 hours for engines below 175 horsepower and 4,500 hours for engines above 175 horsepower, both of which are the minimum allowable maintenance intervals specified in our regulations (i.e., manufacturers are precluded by regulation from requiring more frequent maintenance, and we believe they may require less frequent maintenance than these minimum allowable maintenance intervals). We have estimated costs associated with the maintenance at $65 for engines up to 600 horsepower and $260 per event for engines above 600 horsepower. The calculations for CDPF maintenance are shown in Table 6.2-27. Weighting the savings shown by the fuel use weightings shown in the table, we can calculate these costs as 0.6 cents per gallon which would be incurred only by new engines equipped with a CDPF.[40]

Operating costs associated with CDPF maintenance are attributed only to PM control.

Table 6.2-27
CDPF Maintenance Costs for New CDPF-Equipped Engines ($2001)

PM Filter Maintenance Costs	Units	Nonroad Engines							
Rated Power	hp	0-25	25-50	50-75	75-175	175-300	300-600	600-750	750+
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.38996	0.367	0.367	0.367	0.367
Fuel Density	lbm/gallon	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Population Weighted Avg. Horsepower	hp	18	37	67	113	223	381	717	1263
Population Weighted Avg. Activity	hrs/year	524	579	707	696	525	585	931	921
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.44	0.47	0.56	0.56	0.55	0.54
Filter Maintenance Interval	hours	3,000	3,000	3,000	3,000	4,500	4,500	4,500	4,500
Filter Maintenance Cost Materials	$/event	$0	$0	$0	$0	$0	$0	$0	$0
Filter Maintenance Labor	$/event	$65	$65	$65	$65	$65	$65	$130	$260
Total Filter Maintenance Cost per event	$/event	$65	$65	$65	$65	$65	$65	$130	$260
Fuel Use Between Maintenance Interval	gallons/period	1,272	2,807	5,082	8,751	29,048	49,629	91,728	158,642
Maintenance Cost	$/gallon	$0.051	$0.023	$0.013	$0.007	$0.002	$0.001	$0.001	$0.002
Fuel Use Weightings	% total	2.4%	5.1%	14.0%	26.3%	23.0%	17.7%	4.1%	7.5%

Labor costs are from ICF Consulting under contract to EPA.[41]

6.2.3.3 Operating Costs Associated with Fuel Economy Impacts on New Engines

6.2.3.3.1 What Would the Fuel Economy Impacts Be?

The high efficiency emission control technologies expected to be applied to meet the PM standards for engines greater than 25 horsepower and the NOx standards for engines greater than 75 horsepower involve wholly new system components integrated into engine designs and calibrations and, as such, may be expected to change the fuel consumption characteristics of the overall engine design. After reviewing the likely technology options available to the engine manufacturers, we believe that the integration of the engine and exhaust emission control systems into a single synergistic emission control system will lead to nonroad engines which can meet demanding emission control targets with only a small impact on fuel consumption. Technology improvements have historically eliminated these marginal impacts in the past and it is our expectation that this kind of continuing improvement will eliminate the modest impact estimated here. However, because we cannot project the timeframe for this improvement to be realized, we have conservatively included this impact in our cost estimates for the full period of the program.

6.2.3.3.1.1 CDPF Systems and Fuel Economy

Diesel particulate filters are anticipated to provide a step-wise decrease in diesel particulate (PM) emissions by trapping and oxidizing the diesel PM. The trapping of the very fine diesel PM is accomplished by forcing the exhaust through a porous filtering media with extremely small openings and long path lengths.[F] This approach results in filtering efficiencies for diesel PM greater than 90 percent but requires additional pumping work to force the exhaust through

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[F] Typically, the filtering media is a porous ceramic monolith or a metallic fiber mesh. We refer to it as a “filter trap” in Table 6.2-11.

these small openings. The impact of this additional pumping work on fuel consumption is dependent on engine operating conditions. At low exhaust flow conditions (i.e., low engine load, low turbocharger boost levels), the impact is so small that it can typically not be measured, while at very high load conditions, with high exhaust flow conditions, the fuel economy impact can be as large as one to two percent.[42,43] We have estimated that the average impact of this increased pumping work will be equivalent to an increase fuel consumption of approximately one percent.[44]

Under conditions typical of much of nonroad engine operation, the soot stored in the PM filter will be regenerated passively using the heat of the exhaust gas promoted by catalyst materials. We have performed an analysis of the expected exhaust temperatures for a number of typical in-use operating cycles in Chapter 4.1.3 of this draft RIA. That analysis shows that for a many nonroad engines passive regeneration can be expected. Under some conditions including very low ambient temperatures, or extended low load operation, the exhaust temperature of the engine may not be hot enough to ensure complete passive regeneration. To address this situation, we believe that some manufacturers will need to employ active backup regeneration systems that provide supplemental heat to initiate regeneration as discussed in Chapter 4.1 of this Draft RIA and, as explained in Section 6.2.2.3, we are costing active regeneration systems for all engines using a CDPF system. We have estimated a cost for active regeneration systems for all engines even though CDPF systems on many nonroad engines are expected to regenerate passively. We have done this because we think that it is unlikely that nonroad engine manufacturers will be able to accurately predict which engines will be operated in a manner conducive to passive regeneration and which engines will require periodic active regeneration. There will be no fuel economy impact for nonroad engines that have an active regeneration technology but which in-use experience passive regeneration. Examples of active PM filter systems today, that do not benefit from low sulfur diesel fuel, nor catalytic coatings to promote regeneration, require additional fuel supplementation of approximately two percent for active filter regeneration.[45] Given the clean diesel fuel proposed in this rulemaking, the ability to use catalytic coatings to promote soot oxidation and the fact that many kinds of nonroad equipment are expected to be operated in a manner such that passive regeneration will occur, we believe that the average fuel economy impact of the backup regeneration systems will be no larger than one percent.

We have projected that engines in the horsepower category from 25 hp to 75 horsepower will comply with the PM standard of 0.02 g/bhp-hr using a CDPF system including a backup active regeneration system. The NOx control systems expected in this horsepower category are not advanced catalyst based systems and, as such, have limited ability to recover fuel economy through timing advance or other in-cylinder NOx control strategies as discussed below. Therefore, we project that a two percent fuel economy impact (i.e. one percent due to backpressure and one percent due to use of backup regeneration systems) will be realized by engines in this category from 25 hp to 75 hp. We believe that it is likely that in the long term this impact will be recovered through continuing technology refinement as has historically happened. However, to be conservative in our cost analysis, we have included this two percent impact for the entire duration of the program.

For engines in the horsepower category below 25 hp we have projected no need to use CDPF technologies to comply with the proposed PM standard. Therefore, no fuel consumption impact from the CDPF is estimated for this category.

We believe all engines in the horsepower categories above 75 hp will use integrated NOx and PM control technologies to comply with the emission standards proposed today. The advanced catalyst based emission control technology that we project industry will use to comply with the proposed NOx standard offers the opportunity to improve fuel economy as described in the following section. Based on those projected improvements, we have estimated that the net impact on fuel consumption for engines greater than 75 hp due to the CDPF technology and the NOx technology to be one percent. Future technology improvements are likely to recover this fuel consumption impact; however, to be conservative in our cost analysis, we have assumed that a one percent fuel consumption impact persists for the period of the emission control program.

6.2.3.3.1.2 NOx Control and Fuel Economy

NOx adsorbers are expected to be the primary NOx control technology introduced in order to provide the reduction in NOx emissions for engines greater than 75 hp. NOx adsorbers work by storing NOx emissions under fuel lean operating conditions (normal diesel engine operating conditions) and then by releasing and reducing the stored NOx emissions over a brief period of fuel rich engine operation. This brief periodic NOx release and reduction step is directly analogous to the catalytic reduction of NOx over a gasoline three-way catalyst. In order for this catalyst function to occur the engine exhaust constituents and conditions must be similar to normal gasoline exhaust constituents. That is, the exhaust must be fuel rich (devoid of excess oxygen) and hot (over 250°C). Although it is anticipated that nonroad diesel engines like on-highway diesel engines can be made to operate in this way, it is anticipated that fuel economy while operating under these conditions will be worse than normal. This increase in fuel consumption can be minimized by carefully controlling engine air-to-fuel (A/F) ratios using the control systems we anticipate will be used to meet the Tier 3 emission standards. The lower the engine A/F ratio, the lower the amount of fuel which must be added in order to give rich conditions. In the ideal case where the engine A/F ratio is at stoichiometry, and additional fuel is required only as a NOx reductant the fuel economy penalty is virtually zero. We are projecting that practical limitations on engine A/F control will mean that the NOx adsorber release and reduction cycles will lead to a one percent decrease in the engine fuel economy.[46] We estimate that this fuel economy impact can be regained through optimization of the engine-PM trap-NOx adsorber system, as discussed below.

In addition to the NOx release and regeneration event, another step in NOx adsorber operation may affect fuel economy. As discussed earlier, NOx adsorbers are poisoned by sulfur in the fuel even at the low sulfur levels proposed today. As discussed in chapter 4 of this Draft RIA, the sulfur poisoning of the NOx adsorber can (and must) be reversed through a periodic "desulfation" event. The desulfation of the NOx adsorber is accomplished in a similar manner to the NOx release and regeneration cycle described above. However it is anticipated that the desulfation event will require extended operation of the diesel engine at rich conditions.[47] This rich operation will, like the NOx regeneration event, require an increase in the fuel consumption rate and will cause an associated decrease in fuel economy. This loss in fuel consumption is directly proportional to the amount of sulfur in diesel fuel. The frequency of desulfation is therefore a function of the fuel sulfur level and the fuel consumption rate. Since the desulfation frequency and the associated fuel consumption impacts are proportional only to fuel rate and to fuel sulfur levels, the projected fuel consumption impacts at 15 ppm sulfur are the same for on-highway and nonroad diesel engines. With a 15 ppm fuel sulfur cap, we are projecting that fuel consumption for desulfation would increase by no more than one percent, which we believe can be regained through optimization of the engine-CDPF-NOx adsorber system as discussed below.

While NOx adsorbers require non-power producing consumption of diesel fuel in order to function properly and, therefore, have an impact on fuel economy, they are not unique among NOx control technologies in this way. In fact NOx adsorbers are likely to have a very favorable NOx to fuel economy trade-off when compared to our projected Tier 3 NOx control technologies, cooled EGR and injection timing retard. EGR requires the delivery of exhaust gas from the exhaust manifold to the intake manifold of the engine and causes a decrease in fuel economy for two reasons. The first of these reasons is that a certain amount of work is required to pump the EGR from the exhaust manifold to the intake manifold; this necessitates the use of intake throttling or some other means to accomplish this pumping. The second of these reasons is that heat in the exhaust, which is normally partially recovered as work across the turbine of the turbocharger, is instead lost to the engine coolant through the cooled EGR heat exchanger. In the end, cooled EGR is approximately 50 percent effective at reducing NOx below the current Tier 2 NOx levels. Injection timing retard is another strategy that can be employed to control NOx emissions. By retarding the introduction of fuel into the engine, and thus delaying the start of combustion, both the peak temperature and pressure of the combustion event are decreased; this lowers NOx formation rates and, ultimately, NOx emissions. Unfortunately, this also significantly decreases the thermal efficiency of the engine (lowers fuel economy) while also increasing PM emissions. As an example, retarding injection timing eight degrees can decrease NOx emissions by 45 percent, but this occurs at a fuel economy penalty of more than seven percent.[48]

Nonroad Tier 2 diesel engines rely primarily on charge-air-cooling and injection timing control (retarding injection timing) in order to meet the Tier 2 NOx+NMHC emission standard. For Tier 3 compliance, we expect that engine manufacturers will use a combination of cooled EGR and injection timing control to meet the NOx standard. Because of the more favorable fuel economy trade-off for NOx control with EGR when compared to timing control, we have forecast that less reliance on timing control will be needed in Tier 3, when compared to Tier 2. Therefore, fuel economy will not be changed even at this lower NOx level. Similarly for the 25-50 hp engines which would need to meet a 3.3 g/bhp-hr Tier 4 NOx emission limit under today's proposal, we believe that there will be no change in fuel consumption due to the NOx standard. NOx adsorbers have a significantly more favorable NOx to fuel economy trade-off when compared to cooled EGR or timing retard.[49] We expect NOx adsorbers to be able to accomplish a greater than 90 percent reduction in NOx emissions, while themselves consuming significantly less fuel than that lost through alternative NOx control strategies such as retarded injection timing.[G] Therefore, we expect manufacturers to take full advantage of the NOx control capabilities of the NOx adsorber and project that they will decrease reliance on the more expensive (from a fuel economy standpoint) technologies, especially injection timing retard. We would, therefore, predict that the fuel economy impact currently associated with NOx control from timing retard will be decreased by at least three percent. In other words, through the application of advanced NOx emission control technologies, which are enabled by the use of low sulfur diesel fuel, we expect the NOx trade-off with fuel economy to continue to improve significantly when compared to today's technologies. This will result in both much lower NOx emissions, and potentially overall improvements in fuel economy. Improvements could easily offset the fuel consumption of the NOx adsorber itself and, in addition, at least half of the fuel economy impact projected to result from the application of the CDPF technology. Consequently, we are projecting a one percent fuel economy impact to result from this rule for engines in the horsepower categories above 75 hp.

6.2.3.3.1.3 Fuel Economy Impacts for Engines without Advanced Emission Control Technologies (engines <25 horsepower)

The emission standard proposed today for engines below 25 hp does not change the NOx emission standard from the current Tier 2 level. The PM standard, however, is reduced by almost 50%. We believe that this significant PM reduction will be realized through improvements in combustion system design, improvements in fuel system design and utilization and through the use of diesel oxidation catalysts (DOCs). DOCs are expected to have no measurable effect on fuel consumption. However, changes to the engine designed to reduce PM emissions could lead to a reduction in fuel consumption, at least for direct injected diesel engines. The potential range for improved fuel economy for engines of this size is unknown but experience with changes to engine design that improve combustion and reduce PM suggest that the improvement could be significant. However, because of the difficulty in projecting the future ratio of direct-injected and indirect-injected diesel engines for this portion of the nonroad market and the first order affect that this ratio has on average fleet consumption we have not attempted to account for this potential fuel economy improvement in our cost analysis. Therefore, no change in fuel consumption is estimated in our cost analyses for engines with rated power below 25 hp.

6.2.3.3.2 Costs Associated with these Fuel Economy Impacts

To calculate the costs associated with these fuel economy impacts, we have used a diesel fuel price, minus taxes, of 60 cents per gallon. To that, we have added the incremental cost per gallon

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[G] EPA has estimated the fuel consumption rate for NOx regeneration and desulfation of the NOx adsorber as approximately 2 percent of total engine fuel consumption. This differs from an EPA contractor report by EF&EE which estimates the total consumption as approximately 2.5% of total fuel consumption. Additionally the contractor's estimate of NOx adsorber efficiency ranges from 80-90 percent, while EPA believes over 90 percent control is possible as discussed fully in Chapter 4 of this draft RIA.

for 15 ppm fuel where appropriate. These incremental fuel costs are discussed in Chapter 7 of this Draft RIA as 4.8 cents per gallon. This increased operating cost – 60 cents plus 4.8 cents – is applied to only those gallons of fuel consumed in engines equipped with technologies for which a fuel economy impact would be realized. For 25 to 50 horsepower engines, where we estimate a two percent impact, the incremental cost would be 1.3 cents per gallon (2%*64.8 cents/gallon). For >75 horsepower engines, where we estimate a one percent fuel economy impact, the incremental cost would be 0.65 cents per gallon.

Operating costs associated with fuel economy impacts are attributed only to PM control.

6.2.3.4 Operating Costs Associated CCV Maintenance on New Engines

For CCV systems, we have used a maintenance interval of 675 hours for all engines and a cost per maintenance event of $8 to $48 for small to large engines. The 675 maintenance interval is chosen as twice the oil change maintenance interval. CCV maintenance is assumed to be done during every other oil change event; this results in $0 labor cost for CCV maintenance. The calculation of operating costs associated with CCV maintenance are shown in Table 6.2-28. On a weighted basis, these costs are 0.2 cents per gallon and would be incurred only by new engines equipped with a CDPF.

Operating costs associated with CCV maintenance are attributed evenly to NOx and PM control.

Table 6.2-28
Closed Crankcase Ventilation System
Maintenance Costs for New Turbo-Charged Engines ($2001)

CCV Maintenance Costs	Units								
Rated Power	hp	0-25	25-50	50-75	75-175	175-300	300-600	600-750	750+
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.38996	0.367	0.367	0.367	0.367
Fuel Density	lbm/gallon	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Population Weighted Avg. Horsepower	hp	18	37	67	113	223	381	717	1263
Population Weighted Avg. Activity	hrs/year	524	579	707	696	525	585	931	921
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.44	0.47	0.56	0.56	0.55	0.54
CCV Filter Replacement Interval	hours	675	675	675	675	675	675	675	675
CCV Filter Replacement Cost	$/event	$8	$8	$8	$8	$10	$12	$24	$48
Filter Maintenance Labor	$/event	$0	$0	$0	$0	$0	$0	$0	$0
Total Filter Maintenance Cost per event	$/event	$8.00	$8.00	$8.00	$8.00	$9.60	$12.00	$24.00	$48.00
Fuel Use Between Maintenance Interval	gallons/period	286	631	1,143	1,969	4,357	7,444	13,759	23,796
Turbcharged Fleet Fraction	[%]	0%	5%	41%	41%	73%	100%	100%	100%
Maintenance Cost	$/gallon	$0.028	$0.013	$0.007	$0.004	$0.002	$0.002	$0.002	$0.002
Fuel Use Weightings	% total	0.0%	0.2%	5.7%	10.7%	16.9%	17.7%	4.1%	7.5%

6.3 Equipment-Related Costs

Costs of control to equipment manufacturers include fixed costs (those costs for equipment redesign and for tooling), and variable costs (for new hardware and increased equipment assembly time). According to the PSR Sales Database for the year 2000,[50] there are approximately 600 nonroad equipment manufacturers using diesel engines in several thousand different equipment models. We realize that the time needed for equipment manufacturers to make the necessary changes on such a large number of equipment models will vary significantly from manufacturer to manufacturer and from application to application. One of the goals of the proposed transition program for equipment manufacturers (TPEM) is to reduce the potential for anomalously high costs for individual equipment models by providing significant additional time (up to 7 years) for developing less costly designs or to align the changes with an already scheduled redesign. To present a conservative estimate of equipment-related costs, we have assumed that the industry does not use the TPEM program which, we believe, offers the opportunity for significant cost reductions. However, in Section 6.3.3 of this Draft RIA we present an analysis of the potential cost savings of the TPEM program.

6.3.1 Equipment Fixed Costs

6.3.1.1 Equipment Redesign Costs

The projected modifications to equipment resulting from the proposed standards relate to packaging of the exhaust emission control hardware expected to be added by engine manufacturers to their new engines (see Section 6.2 for cost estimates of new emission control hardware). As noted in Section 6.2, the additional emission control hardware is proportional in size to engine displacement by a 4:1 ratio (1.5x engine displacement for both the CDPF and the NOx adsorber, and 1x displacement for the DOC that is part of the NOx adsorber system). We expect that equipment manufacturers will have to redesign their equipment to accommodate this new volume of hardware. We expect that some redesigns would be major in scale, while others would be minor in scale. For example, in some cases, the redesign would simply be bolting the new devices onto the existing design, but in most cases we expect devices to be designed into the piece of equipment such that their presence would not be obvious to the casual observer. Additionally, a redesign to accommodate a DOC (1x engine displacement) should be less intensive than a redesign to accommodate a CDPF/NOx adsorber system. Lastly, for >75 horsepower engines where proposed NOx standards are phased-in, we assume that the redesign effort for those final NOx phase-in pieces of equipment (i.e., when the phase-in goes from 50 percent to 100 percent) would be less costly than the first redesign effort.

6.3.1.1.1 Schedule of Equipment Redesigns

The proposal contains a variety of emission compliance dates for the range of nonroad diesel engines; these dates are as shown in Table 6.3-1. For this analysis, because we are assuming no use of the TPEM program, we assume that the timing of equipment redesigns would correlate to the implementation of the proposed engine standards assuming no use of the engine ABT program. This results in a redesign schedule as shown in Table 6.3-1. We have noted what percentage of equipment models would be redesigned in years for which proposed engine standards would be implemented. The table also notes what percentage are major redesign efforts and what percentage are minor efforts. We also note what percentage of the redesign costs are allocated to PM and what percentage to NOx.

Table 6.3-1
Equipment Redesign Assumptions for Equipment Manufacturers

Horsepower	Engine Standard Dates	Pollutant Allocation	Percent of Equipment Models Undergoing Minor Redesign	Percent of Equipment Models Undergoing Major Redesign
0<hp<25	2008	100% PM	100%	
25<=hp<50	2008	100% PM	100%	
	2013	50% PM 50% NOx		100%
50<=hp<75	2008	100% PM	100%	
	2013	100% PM		100%
75<=hp<175	2012	50% PM 50% NOx		100%
	2014	100% NOx	50%	
175<=hp<=750	2011	50% PM 50% NOx		100%
	2014	100% NOx	50%	
>750hp	2011	50% PM 50% NOx		50%
	2014	50% PM 50% NOx		50%

Note that we have assumed that all equipment redesigns for the 75 to 750 horsepower range are major in the first year of proposed engine standards and minor in the last year. The costs associated with such minor redesign efforts are assumed to be half those associated with major redesign efforts. We have done this because we believe that equipment manufacturers would expend less effort to redesign those pieces equipment needing to add only the NOx adsorber (in those years where NOx phase-ins change from 50 percent to 100 percent) for three reasons: (1) these models would already have been redesigned for the CDPF system and would already incorporate the necessary electronic systems into their design; (2) equipment manufacturers would, presumably, have gained experience during the major redesign phase that should make the minor redesign phase more efficient; and, (3) manufacturers aware of the future requirement will be able to make provisions in the first redesign that account for future needs. Therefore, the second redesign effort should be less intensive. For engines over 750 horsepower, we have projected that 50 percent of the engines would be redesigned to incorporate a CDPF/NOx adsorber system in 2011 with the remaining 50 percent being modified in 2014. These projections are consistent with the phase-in of the proposed standards; both redesign efforts are assumed to be major since we assume that the NOx phase-in engines/equipment would be the same as the PM phase-in engines/equipment.

Our equipment redesign cost estimates were developed based on our meetings and conversations with engine and equipment manufacturers, specific redesign cost estimates provided by equipment manufacturers for the redesign of equipment to accommodate engines meeting the Tier 2 standards, and our engineering judgment as needed. The following section details our assessment of costs to equipment manufacturers.

6.3.1.1.2 Costs of Equipment Redesigns

While developing our equipment redesign cost estimates for the proposed Tier 4 standards, we met with a wide range of equipment manufacturers. This included equipment manufacturers with annual revenues less than $50 million and engineering staffs of less than 10 employees, equipment manufacturers with annual revenues on the order of $200 million and engineering staffs on the order of 50 employees, and equipment manufacturers with annual revenue well in excess of $1 billion with annual research and development budgets of more than $100 million and engineering staffs of more than 500 employees.

During these meetings and discussions, it became apparent to us that, in spite of the significant engine technology differences between Tier 2/3 and Tier 4, the impact on equipment design and the need for redesign are similar. That is, for Tier 2, many engines have added electronic fuel systems, turbocharging, and charge-air-cooling. In addition, many Tier 2 engines rely on retarded fuel injection to lower NOx emissions, which therefore increase heat rejection and require the equipment manufacturers to install larger radiators and fans. The process of equipment redesign for Tier 2 involved engineering work to accommodate these new components (e.g., charge-air-coolers, turbochargers, larger radiators and fans) and electronic fuel systems. In many respects, this is similar to what will be required for Tier 4, where those engines which don’t have electronic fuel systems will require them, and equipment manufacturers will now need to integrate aftertreatment systems (as compared to charge-air-coolers, turbochargers, larger radiators and fans).

A number of the companies we met with in the past year provided us with specific redesign cost information for the existing nonroad standards, and in some cases projections for equipment redesigns necessary to integrate aftertreatment (these data are confidential business information). In addition to the companies we met with in the past year, we also received redesign cost estimates from a number of equipment companies during the Tier2/3 rulemaking regarding their projected costs for the Tier 2 standards (these data are confidential business information). The information provided to EPA through these various channels showed that there is a very wide range of cost estimates and actual cost data for redesigning nonroad equipment for the Tier 2 standards. In general, what we learned was those very large companies tend to allocate significantly more resources to equipment redesign than the medium or small companies.

We have used all this information and data, and our engineering judgement, to develop the redesign cost estimates presented in Table 6.3-2. This table presents fixed cost per motive and non-motive equipment model (motive equipment is that with some form of propulsion system while non-motive equipment has none, e.g., air compressors, generator sets, hydraulic power units, irrigation sets, pumps and welders) for each horsepower group. In general, non-motive equipment has fewer design demands than does motive equipment – no operator line-of-sight demands, fewer serviceability constraints, and almost no impact (collision) concerns. As a result, we have estimated a lower redesign cost for non-motive equipment relative to motive equipment.

Table 6.3-2
Estimated Equipment Redesign Costs Per Model

Horsepower	Motive	Non-Motive
0<hp<25	$50,000	$50,000
25<=hp<50		
2008	$50,000	$50,000
2013	$187,500	$75,000
50<=hp<75	$350,000	$100,000
75<=hp<100	$350,000	$100,000
100<=hp<175	$500,000	$100,000
175<=hp<300	$500,000	$100,000
300<=hp<600	$750,000	$100,000
600<=hp<=750	$750,000	$100,000
>750hp	$750,000	$100,000

Using the PSR database we were able to determine the number of equipment models and the type of equipment model (motive versus non-motive). We distinguished motive from non-motive using our Nonroad Model definition of stationary applications. Non-motive applications include air compressors, generator sets, pumps, hydraulic power units, irrigation sets, and welders. All other applications are considered motive.

6.3.1.2 Costs Associated with Changes to Product Support Literature

Equipment manufacturers are also expected to modify product support literature (dealer training manuals, operator manuals, service manuals, etc.) due to the product changes resulting from the new emission standards. For each product line of motive applications, we estimated that the level of effort needed by equipment manufacturers to modify the support literature would be about 100 hours – 75 hours of junior engineering time, and 20 hours of senior engineering time, and 5 hours of clerical time – which would be about $10,000. We projected that the level of effort needed by equipment manufacturers to modify support literature for each non-motive application product line would be about 50 hours (distributed similarly), which is equivalent to about $5,000. Table 6.3-3 contains the total costs per power category for changes to support literature.

Table 6.3-3
Costs Associated with Changes to Product Support Literature ($1,000's)

Horsepower	Motive models	Motive Cost	Non-motive models	Non-motive cost	Total Cost
0<hp<25	561	$5,610	159	$795	$6,405
25<=hp<50	705	$7,050	169	$845	$7,895
50<=hp<75	496	$4,960	138	$690	$5,650
75<=hp<100	722	$7,220	146	$730	$7,950
100<=hp<175	1289	$12,890	223	$1,115	$14,005
175<=hp<300	1222	$12,220	227	$1,135	$13,355
300<=hp<600	677	$6,770	178	$890	$7,660
600<=hp<=750	127	$1,270	0	$0	$1,270
>750hp	117	$1,170	0	$0	$1,170

6.3.1.3 Total Equipment Fixed Costs

The annual equipment fixed costs for each horsepower category are shown in Table 6.3-4. As was done for engine fixed costs, we have attributed only a portion of the equipment fixed costs to sales within the United States. We have done this because we believe that these efforts would be needed to sell equipment not only in the US, but also in Australia, Canada, Japan, and the countries of the European Union. Therefore, as was discussed in more detail in section 6.2.1.1, we have attributed 42 percent of the equipment fixed costs to U.S. sales.

The analysis projected that the costs would be incurred over a two year period prior to the first year of the emission standards. The costs were then amortized over 10 years at a seven percent rate beginning with the first year of the engine standard to reflect the time value of money. The 10 year period for amortization, as opposed to the five year period used for engine costs, reflects the longer product development cycles for equipment relative to engines.

Per unit fixed costs are shown in Table 6.3-5 and use our projections of engine growth as presented in Table 8-1.

Table 6.3-4

Recovered (Annualized) Equipment Fixed Costs per Horsepower Category ($2001, in thousands of dollars)

Year	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<100	100<=hp<175	175<=hp<300	300<=hp<600	600<=hp<=750	>750hp	Total
2008	$1,541	$1,938	$1,372	$0	$0	$0	$0	$0	$0	$4,852
2009	$1,541	$1,938	$1,372	$0	$0	$0	$0	$0	$0	$4,852
2010	$1,541	$1,938	$1,372	$0	$0	$0	$0	$0	$0	$4,852
2011	$1,541	$1,938	$1,372	$0	$0	$19,941	$17,526	$3,246	$1,693	$47,257
2012	$1,541	$1,938	$1,372	$7,811	$19,662	$19,941	$17,526	$3,246	$1,693	$74,730
2013	$1,541	$7,261	$5,383	$7,811	$19,662	$19,941	$17,526	$3,246	$1,693	$84,064
2014	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2015	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2016	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2017	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2018	$0	$5,323	$4,011	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$97,952
2019	$0	$5,323	$4,011	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$97,952
2020	$0	$5,323	$4,011	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$97,952
2021	$0	$5,323	$4,011	$9,764	$24,578	$4,985	$4,381	$811	$1,693	$55,547
2022	$0	$5,323	$4,011	$1,953	$4,916	$4,985	$4,381	$811	$1,693	$28,074
2023	$0	$0	$0	$1,953	$4,916	$4,985	$4,381	$811	$1,693	$18,740
Total	$15,413	$72,610	$53,832	$97,642	$245,775	$249,256	$219,073	$40,570	$33,867	$1,028,036

Table 6.3-5

Recovered Equipment Fixed Cost per Unit ($2001)

	0<hp<25		25<=hp<50		50<=hp<75		75<=hp<100	
Year	Sales	$/unit	Sales	$/unit	Sales	$/unit	Sales	$/unit
2008	152,087	$10	161,021	$12	110,279	$12	80,659	$0
2009	156,203	$10	164,526	$12	112,325	$12	82,158	$0
2010	160,319	$10	168,031	$12	114,371	$12	83,657	$0
2011	164,435	$9	171,536	$11	116,416	$12	85,157	$0
2012	168,551	$9	175,041	$11	118,462	$12	86,656	$90
2013	172,667	$9	178,546	$41	120,507	$45	88,155	$89
2014	176,783	$9	182,051	$40	122,553	$44	89,654	$109
2015	180,899	$9	185,556	$39	124,599	$43	91,154	$107
2016	185,015	$8	189,061	$38	126,644	$43	92,653	$105
2017	189,131	$8	192,566	$38	128,690	$42	94,152	$104
2018	193,247	$0	196,071	$27	130,736	$31	95,652	$102
2019	197,363	$0	199,576	$27	132,781	$30	97,151	$101
2020	201,479	$0	203,081	$26	134,827	$30	98,650	$99
2021	205,595	$0	206,586	$26	136,872	$29	100,149	$97
2022	209,711	$0	210,091	$25	138,918	$29	101,649	$19
2023	213,827	$0	213,596	$0	140,964	$0	103,148	$19

	100<=hp<175		175<=hp<300		300<=hp<600		600<=hp<=750		>750hp	
Year	Sales	$/unit	Sales	$/unit	Sales	$/unit	Sales	$/unit	Sales	$/unit
2008	130,909	$0	73,163	$0	37,583	$0	3,152	$0	3,193	$0
2009	133,230	$0	74,577	$0	38,019	$0	3,202	$0	3,244	$0
2010	135,551	$0	75,991	$0	38,455	$0	3,252	$0	3,295	$0
2011	137,872	$0	77,405	$258	38,891	$451	3,302	$983	3,346	$506
2012	140,193	$140	78,819	$253	39,327	$446	3,352	$968	3,397	$498
2013	142,514	$138	80,233	$249	39,763	$441	3,402	$954	3,448	$491
2014	144,836	$170	81,647	$305	40,199	$545	3,452	$1,175	3,499	$968
2015	147,157	$167	83,061	$300	40,635	$539	3,502	$1,158	3,550	$954
2016	149,478	$164	84,475	$295	41,071	$533	3,552	$1,142	3,601	$940
2017	151,799	$162	85,889	$290	41,507	$528	3,602	$1,126	3,652	$927
2018	154,120	$159	87,303	$286	41,943	$522	3,652	$1,111	3,703	$915
2019	156,441	$157	88,717	$281	42,379	$517	3,702	$1,096	3,754	$902
2020	158,762	$155	90,131	$277	42,815	$512	3,752	$1,081	3,805	$890
2021	161,083	$153	91,545	$54	43,251	$101	3,802	$213	3,856	$439
2022	163,404	$30	92,959	$54	43,687	$100	3,852	$211	3,907	$433
2023	165,725	$30	94,373	$53	44,123	$99	3,902	$208	3,958	$428

Costs per unit vary from year to year due to proposed standard phase-ins. The rapid decline in per unit costs during the final two or three years for >75 horsepower engines is because the latter redesign work – to accommodate the final year of the NOx phase-in – is considered a minor and less costly redesign, as was discussed above.

6.3.2 Equipment Variable Costs

In addition to the incrementally higher cost of new engines estimated in section 6.2.1 and 6.2.2, equipment manufacturers would need to purchase hardware to mount the new exhaust emission control devices within each newly redesigned piece of equipment. Note that the redesign costs we have already discussed are for changes in equipment design to accommodate aftertreatment devices. We assume that there are minimal changes to the variable costs for the redesigned elements of the equipment (i.e., the redesigned elements cost roughly the same as before) because they serve the same function and contain the same amount of materials. Here, we estimate the costs associated with the new hardware that will be necessary – new brackets, bolts, and sheet metal – for mounting and housing the new aftertreatment devices.

Here, we estimate the cost for additional sheet metal that could be used to shroud or otherwise encase aftertreatment system within the confines of the hood or other body cladding on a piece of equipment. The amount of metal for the shroud was determined using the engine displacement per equipment model information in the 2002 PSR Sales Database. The volume of the CDPF and NOx adsorber aftertreatment was calculated for each model in the PSR database which incorporated an engine over 75hp (1.5 times engine displacement for CDPF and the same for NOx adsorber). The DOC was assumed to fit in place of the muffler. The volume of the aftertreatment was then converted to the volume of a cube and two inches were added to each dimension for space between the aftertreatment and the shroud. Sheet metal was assumed to cover four sides of the aftertreatment with no cover for the bottom or equipment facing side of the shroud. Sheet metal was assumed to cost $1.10 per square foot for hot rolled steel. The cost for each model was multiplied by the total sales for that model using the 2000 sales information in the 2002 PSR Sales Database. The total costs were summed for each power group and then divided by the total sales for the power group for a sales weighted average cost. These costs were then added to variable cost estimates for brackets and bolts required to secure the aftertreatment devices within the equipment, other such miscellaneous items including weldments, plastics, castings, gaskets, seals, and hoses, as well as the labor required to install the new aftertreatment devices. A twenty-nine percent markup for overhead and profit is also included in the final cost estimate as shown in Table 6.3-6.

Table 6.3-6
Equipment Variable Costs[a]

Horsepower	Year	Bolts	Sheet Metal	Labor	Subtotal	29% Markup	Total
0<hp<25	2008	$0	$0	$0	$0	$0	$0
25<=hp<50	2013	$4	$0	$10	$14	$4	$18
50<=hp<75	2013	$4	$0	$10	$14	$4	$18
75<=hp<100	2012	$20	$3	$20	$42	$12	$55
100<=hp<175	2012	$20	$3	$20	$43	$12	$55
175<=hp<300	2011	$20	$5	$29	$54	$16	$70
300<=hp<600	2011	$40	$6	$59	$105	$30	$135
600<=hp<=750	2011	$40	$9	$59	$108	$31	$139
>750hp	2011	$80	$14	$78	$173	$50	$223

[a] Some equipment types have strict surface temperature requirements for exhaust components. Air gapping and water jacketing systems are on such engines and would likely be extended to include the area of the aftertreatment. Such costs are not included in this analysis for these costs would only apply to specialized equipment (<1%). However, costs have been calculated in a memo to the docket (docket A-2001-28).

As shown in Table 6.3-6, we have estimated equipment variable costs for less than 25 horsepower equipment to be $0 under the assumption that an added DOC would replace the existing muffler and make use of the same bracket/bolt/labor used for the muffler. This is also assumed for engines in the 25 to 75 horsepower range during the years 2008 through 2012 when only a DOC is being used by the engine manufacturer for compliance; additional bolts and labor costs are added for the addition of a CDPF beginning in 2013.[H] While we have assumed the CDPF will simply replace the muffler, there will be additional bracket/bolt/labor demands due to the greater weight of the CDPF relative to the replaced muffler.

6.3.3 Potential Impact of the Transition Provisions for Equipment Manufacturers

As discussed in Section VII.B of the preamble, we have proposed to extend the Transition Provisions for Equipment Manufacturers (TPEM) which were developed in the 1998 nonroad rule into the proposed Tier 4 program (with a number of modifications as discussed in Section VII.B of the preamble). The TPEM is an important component of our proposal because of the flexibility it provides for equipment manufacturers. However, as explained earlier, because the program is optional, we have not included an estimate of the potential impacts of the program on the overall costs of our proposed Tier 4 program. Nevertheless, in this section we discuss why the TPEM program can have a substantial impact reducing equipment manufacturer costs.

[H] Note that, for costing purposes, we have assumed that a DOC is used on all <75 horsepower engines to comply with the 2008 standards although test data suggests that some engines may not need to add a DOC because they would already meet the proposed standards.

The TPEM can reduce equipment manufacturer costs in two ways. First, the proposed Tier 4 TPEM program would allow equipment manufacturers to continue to sell a limited number of equipment with non-Tier 4 engines even after the Tier 4 standards go into effect. Therefore, any engine price increase associated with the proposed Tier 4 standards would not be incurred by the equipment manufacturer or by the end user during the time frame the manufacturers make us of the TPEM. Second, the TPEM program allows manufacturers to schedule equipment design cycles so that the normal redesign cycle can overlap with any redesign necessary because of EPA's emission standards. We believe this is the most significant cost savings impact of the TPEM. This is due to the fact that many equipment manufacturers have a number of small volume equipment model lines. Using the TPEM program, companies can delay the redesign costs associated with Tier 4 engines for up to seven years on a limited number of products.

We performed a detailed analysis on an equipment manufacturer-by-equipment manufacturer basis of the more than 6,000 equipment models and 600 equipment manufacturers contained in an industry-wide database (the Power Systems Research database).[51] This analysis looked at each equipment manufacturers product offerings (e.g., different equipment models) by power category and the estimated 2000 U.S. sales of each equipment model. We used this database to analyze how equipment manufacturers could make use of the proposed TPEM program to maximize the number of equipment models which could take advantage of the TPEM to delay any equipment redesign associated with the proposed Tier 4 standards until the eighth year of the program (as discussed in Section VII.B of the preamble, we have proposed to allow the TPEM program to last until seven years after the Tier 4 standards are implemented.). We specifically analyzed the proposed 80 percent allowance and the small volume option we have requested comment on (as discussed in the preamble). The results are shown in Table 6.3-7.

Table 6.3-7
Potential Impact of TPEM Program on Equipment Models and Sales

Equipment Models/ Equipment Sales	Engine Power Category					
	<25 hp	25< hp <70[a]	70[a]< hp <175	175< hp <750	>750 hp	All Power Categories
% of all equipment **models** which could use TPEM for full-seven years	56%	61%	66%	71%	80%	66%
Percent of equipment **sales** which could use TPEM for full-seven years	7%	10%	13%	12%	21%	10%

a Note, the proposed power ranges are 25-75 and 75-175 hp. This analysis was done using 70 hp as a cut-point. We do not believe the results of this analysis would have been significantly different if the power outpoint was reduce at 75hp.

This analysis indicates that if fully utilized by equipment manufacturers, 66 percent of all of the nonroad diesel equipment models could use the TPEM program to delay an equipment redesign necessary for the Tier 4 standards for seven years. Without the TPEM program, equipment manufactures would need to redesign all of their equipment models which used a nonroad diesel engine in the first year of the engine standard implementation. As an example of the flexibility offered by the TPEM program, Table 6.3-7 indicates that for the 25 - 75 hp category, 61 percent of all equipment models in this power range could take advantage of the TPEM to delay an equipment redesign for seven years. It is important to note that while the

TPEM can substantially reduce equipment redesign costs, it would be expected to have a much smaller impact on the emission reductions of the program. While the TPEM can allow equipment companies to continue selling products with the previous tier standards on many equipment models, the total sales which can be impacted by the TPEM (also shown in Table 6.3-7) is estimated to be no higher than ten percent for no more than seven years.

6.4 Summary of Engine and Equipment Costs

Details of our engine and equipment cost estimates were presented in Sections 6.2 and 6.3. Here we summarize the cost estimates.

6.4.1 Engine Costs

6.4.1.1 Engine Fixed Costs

Engine fixed costs include costs for engine R&D, tooling, and certification. These costs were discussed in detail in Section 6.2.1. The total estimated engine fixed costs are summarized in Table 6.4-1.

Table 6.4-1
Summary of Engine Fixed Costs (millions)

	Incurred Costs	Recovered Costs
R&D	$199	$279
Tooling	$67	$81
Certification	$72	$88
Total	$338	$448

6.4.1.2 Engine Variable Costs

Engine variable costs were discussed in detail in Section 6.2.2. For engine variable costs, we have generated cost estimation equations as a function of engine displacement or number of cylinders. These equations are summarized in Table 6.4-2. Note that not all equations were used for all engines; equations were used in the manner shown in Table 6.4-2. We have calculated the aggregate engine variable costs and present them in Chapter 8 of this Draft RIA. The net present value of these variable costs between the years 2004 through 2036 is $13.9 billion.

Table 6.4-2
Summary of Cost Equations for
Engine Variable Costs (x represents the dependent variable)

Engine Technology	Time Frame[a]	Cost Equation	Dependent Variable (x)	How Used
NOx Adsorber System	Near term Long term	\$105(x) + \$180 \$84(x) + \$158	Displacement[b]	>75hp engines according to phase-in of NRT4 NOx std.
CDPF System	Near term Long term	\$150(x) + \$71 \$114(x) + \$54	Displacement	>25hp engines according to NRT4 PM std.
CDPF Regen System – IDI engines	Near term Long term	\$20(x) + \$289 \$15(x) + \$219	Displacement	IDI engines adding a CDPF
CDPF Regen System – DI engines	Near term Long term	\$10(x) + \$144 \$7(x) + \$110	Displacement	DI engines adding a CDPF
DOC	Near term Long term	\$19(x) + \$117 \$18(x) + \$110	Displacement	<25hp engines beginning in 2008; 25-75hp engines 2008 thru 2012
CCV System	Near term Long term	\$2(x) + \$35 \$2(x) + \$25	Displacement	All turbo-charged engines when they first meet a proposed PM std.
Cooled EGR System	Near term Long term	\$17(x) + \$69 \$13(x) + \$51	Displacement	25-50 hp engines beginning in 2013
Common Rail Fuel Injection (mechanical fuel system baseline)	Near term Long term	\$77(x) + \$627 \$57(x) + \$477	# of cylinders/ injectors	25-50 hp DI engines when they add a CDPF
Common Rail Fuel Injection (electronic rotary fuel system baseline)	Near term Long term	\$66(x) + \$175 \$49(x) + \$132	# of cylinders/ injectors	50-75 hp DI engines when they add a CDPF

[a] Near term = years 1 & 2; Long term = years 3+. Explanation of near term and long term can be found in Section 6.1.

[b] Displacement refers to engine displacement in liters.

6.4.1.3 Engine Operating Costs

Engine operating costs are discussed in detail in Section 6.2.3. Table 6.4-3 summarizes engine operating costs, excluding costs associated with the desulfurization of diesel fuel; these costs are presented in Chapter 7 of this Draft RIA.

Table 6.4-3
Engine Operating Costs Associated with the Proposed Fuel Program
(cents/gallon of fuel consumed)

Horsepower category	Oil Change Savings	CDPF Maintenance	CCV Maintenance	CDPF Regeneration[a]	Net Operating Costs[b]
0<hp<25	(17.5)	0.0	0.0	0.0	(17.5)
25≤hp<50	(8.3)	2.3	1.3	1.30	(3.4)
50≤hp<75	(5.0)	1.3	0.7	1.30	(1.7)
75≤hp<175	(3.2)	0.7	0.4	0.65	(1.5)
175≤hp<300	(2.1)	0.2	0.2	0.65	(1.1)
300≤hp<600	(1.5)	0.1	0.2	0.65	(0.6)
600≤hp<750	(1.1)	0.1	0.2	0.65	(0.2)
>750hp	(1.2)	0.2	0.2	0.65	(0.2)
Locomotive/Marine	(1.1)	0.0	0.0	0.0	(1.1)

[a] A one or two percent fuel consumption increase, a 60 cent/gallon baseline fuel price, and a 4.8 cent/gallon incremental fuel cost.
[b] The incremental costs for the proposed low sulfur fuel are not included here. Fuel costs are presented in Chapter 7 of this Draft RIA.

Engines that make up the existing fleet would realize the oil change savings shown in Table 6.4-3 while incurring none of the other operating costs because these engines would not be equipped with a CDPF system or be adding a CCV system. New engines would incur all the costs and savings shown in Table 6.4-3.

Table 6.4-3 shows operating costs on a cent per gallon basis. Lifetime engine operating costs vary by the amount of fuel consumed. We have calculated lifetime operating costs for some example pieces of equipment and present those in Section 6.5. Aggregate operating costs – the annual total costs – are presented in Chapter 8 of this Draft RIA.

6.4.2 Equipment Costs

6.4.2.1 Equipment Fixed Costs

Equipment fixed costs were discussed in detail in Section 6.3.1. Table 6.4-4 shows estimated equipment fixed costs associated with the proposed program. These costs include costs for equipment redesign and generation of new product support literature.

Table 6.4-4
Summary of Equipment Fixed Costs (millions)

	Incurred Costs	Recovered Costs
Redesign	$678	$999
Product Literature	$19	$29
Total	$697	$1,028

6.4.2.2 Equipment Variable Costs

Equipment variable costs are discussed in detail in Section 6.3.2. Table 6.4-5 shows our estimated per unit equipment variable costs. This table is a repeat of Table 6.3-6.

Table 6.4-5
Equipment Variable Costs per Unit

Horsepower	Year	Bolts	Sheet Metal	Labor	Subtotal	29% Markup	Total
0<hp<25	2008	$0	$0	$0	$0	$0	$0
25<=hp<50	2013	$4	$0	$10	$14	$4	$18
50<=hp<75	2013	$4	$0	$10	$14	$4	$18
75<=hp<100	2012	$20	$3	$20	$42	$12	$55
100<=hp<175	2012	$20	$3	$20	$43	$12	$55
175<=hp<300	2011	$20	$5	$29	$54	$16	$70
300<=hp<600	2011	$40	$6	$59	$105	$30	$135
600<=hp<=750	2011	$40	$9	$59	$108	$31	$139
>750hp	2011	$80	$14	$78	$173	$50	$223

We have calculated the aggregate equipment variable costs in Chapter 8 of this Draft RIA. Those costs show the annual total variable costs we have estimated for our proposal. The net present value of these variable costs between the years 2004 through 2036 is $498 million.

6.5 Costs for Example Pieces of Equipment

6.5.1 Summary of Costs for Some Example Pieces of Equipment

To better illustrate the engine and equipment cost impacts we are estimating for today's proposed standards, we have chosen several example pieces of equipment and presented the estimated costs for them. Using these examples, we can calculate the costs for a specific piece of equipment in several horsepower ranges and better illustrate the cost impacts of today's proposed standards. These costs along with information about each example piece of equipment are shown in Table 6.5-1. Costs presented are near term and long term costs for the final standards to which each piece of equipment would comply. Long term costs are only variable costs and, therefore, represent costs after all fixed costs have been recovered. Included in the table are estimated prices for each piece of equipment to provide some perspective on how our estimated control costs relate to existing equipment prices.

Table 6.5-1
Near Term and Long Term Costs for Several Example Pieces of Equipment[a]
($2001, for the final emission standards to which the equipment must comply)

	GenSet	Skid/Steer Loader	Backhoe	Dozer	Ag Tractor	Dozer	Off-Highway Truck
Horsepower	9 hp	33 hp	76 hp	175 hp	250 hp	503 hp	1000 hp
Displacement (L)	0.4	1.5	3.9	10.5	7.6	18	28
# of cylinders/injectors	1	3	4	6	6	8	12
Aspiration	natural	natural	turbo	turbo	turbo	turbo	turbo
Fuel System	DI	DI	DI	DI	DI	DI	DI
Incremental Engine & Equipment Cost Long Term Near Term	 $120 $170	 $760 $1,100	 $1,210 $1,680	 $2,590 $3,710	 $2,000 $2,950	 $4,210 $6,120	 $6,780 $10,100
Estimated Equipment Price[b]	$3,500	$13,500	$50,000	$235,000	$130,000	$575,000	$700,000
Incremental Operating Costs[c]	-$90	$40	$370	$1,550	$1,320	$4,950	$12,550
Baseline Operating Costs (Fuel & Oil only)[c]	$940	$2,680	$7,960	$77,850	$23,750	$77,850	$179,530

a. Near-term costs include both variable costs and fixed costs; long-term costs include only variable costs and represent those costs that remain following recovery of all fixed costs.
b. "Estimated Price of New Nonroad Example Equipment," memorandum from Zuimdie Guerra to docket A-2001-28.[52]
c. Present value of lifetime costs.

6.5.2 Method of Generating Costs for Our Example Pieces of Equipment

To facilitate the readers ability to duplicate this example analysis for other pieces of equipment, this section will briefly describe the necessary steps to create the cost analysis based on the information contained in this Draft RIA.

The first step required to develop an estimate of our projected cost for control under the proposed Tier 4 program is to define certain characteristics of the engine in the piece of equipment for which a cost estimate is desired. Specifically, the following items must be defined:

- displacement of the engine (i.e., the cylinder swept volume) in liters;
- type of aspiration (i.e., turbocharged or naturally aspirated);
- number of cylinders;
- type combustion system used by the engine (i.e., indirect-injection, IDI, or direct injection, DI);
- model year of production; and,
- the horsepower category of the engine.

With this information, and the data tables contained in this Draft RIA, an estimate of the compliance costs can be made.

As an example, here we will estimate the cost of compliance for the 76hp backhoe in the year 2012. Table 6.5-1 shows the near term cost to be $1,680 and the long term cost to be $1,210. The first step is to define our engine characteristics as shown in Table 6.5-2.

Table 6.5-2
Engine and Equipment Characteristics of an Example Cost Estimate

76 hp Backhoe Example		
Model Year	2012	reader defined
Displacement (liters)	3.9	application specific
Cylinder (number)	4	application specific
Aspiration	Turbocharged	application specific
Combustion System	Direct Injection	application specific
Horsepower Category	75 to 175 hp	regulations define the standards and the timing of the standards

For engines produced in the early years of the program, an accounting of the fixed costs needs to be made. Fixed costs include the engine fixed cost for research and development, tooling, and certification as well as equipment fixed includes including redesign and manual costs. These fixed costs are reported in this chapter on a per engine/piece of equipment basis in each year of the program for which a fixed cost is applied. The necessary numbers to calculate the fixed costs can simply be read from these tables.

Table 6.5-3
Fixed Costs for an Example Cost Estimate

2012 76hp Backhoe Example		
Engine R&D	$27	Table 6.2-4 Engine R&D Costs (per engine)
Engine Tooling	$15	Table 6.2-6 Engine Tooling Costs (per engine)
Engine Certification	$11	Table 6.2-8 Engine Certification Costs (per engine)
Equipment Fixed	$90	Table 6.3-5 Equipment Fixed Cost per Unit
Total Fixed Costs	$143	Summation

The engine variable costs are related to specific engine technology characteristics in a series of linear equations described in table 6.4-2. The table includes all of the different variable cost components for different size ranges of engines meeting different proposed standards. It includes a description of the particular engine categories for which the costs are incurred. The simplest approach to estimating the variable costs is to repeat the table and then to simply zero out any components which do not apply for a particular example (see Table 6.5-4 below).

Table 6.5-4
Summary of Cost Equations for Engine Variable Costs for a 76hp Backhoe Example (x represents the dependent variable)

Engine Technology	Time Frame[a]	Cost Equation	Dependent Variable (x)	How Used
NOx Adsorber System	Near term Long term	\$105(x) + \$180 \$84(x) + \$158	Displacement[b]	>75hp engines according to phase-in of NRT4 NOx std.
2012 76hp Backhoe	2012 is Near Term	\$105 (3.9)+\$180 = \$590	3.9 liters	In 2012 a 76 hp engine in the NOx phase-in set would require a NOx adsorber
CDPF System	Near term Long term	\$150(x) + \$71 \$114(x) + \$54	Displacement	>25hp engines according to NRT4 PM std.
2012 76hp Backhoe	2012 is Near Term	\$150(3.9)+\$71= \$656	3.9 liters	In 2012 all 76hp engines are projected to require CDPFs
CDPF Regen System – IDI engines	Near term Long term	\$20(x) + \$289 \$15(x) + \$219	Displacement	IDI engines adding a CDPF
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	The example engine has a direct injection (DI) combustion system not an indirect injection (IDI)
CDPF Regen System – DI engines	Near term Long term	\$10(x) + \$144 \$7(x) + \$110	Displacement	DI engines adding a CDPF
2012 76hp Backhoe	2012 is Near Term	\$10(3.9)+\$144= \$183	3.9 liters	The example engine is a DI engine and has a CDPF
DOC	Near term Long term	\$19(x) + \$117 \$18(x) + \$110	Displacement	<25hp engines beginning in 2008; 25-75hp engines 2008 thru 2012
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example engine rated power is greater than 75 hp
CCV System	Near term Long term	\$2(x) + \$35 \$2(x) + \$25	Displacement	All turbo-charged engines when they first meet a proposed PM std.
2012 76hp Backhoe	2012 is Near Term	\$2(3.9)+\$35= \$43	3.9 liters	The example engine is turbocharged
Cooled EGR System	Near term Long term	\$17(x) + \$69 \$13(x) + \$51	Displacement	25-50 hp engines beginning in 2013
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example rated power is greater than 50 hp
Common Rail Fuel Injection (mechanical fuel system baseline)	Near term Long term	\$77(x) + \$627 \$57(x) + \$477	# of cylinders/ injectors	25-50 hp DI engines when they add a CDPF
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example rated power is greater than 50 hp
Common Rail Fuel Injection (electronic rotary fuel system baseline)	Near term Long term	\$66(x) + \$175 \$49(x) + \$132	# of cylinders/ injectors	50-75 hp DI engines when they add a CDPF
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example rated power is greater than 75 hp

[a] Near term = years 1 & 2; Long term = years 3+. Explanation of near term and long term can be found in Section 6.1.

[b] Displacement refers to engine displacement in liters.

Summing the applicable variable costs estimated in table 6.5-4 gives a total engine variable cost for the 76hp Backhoe example of $1472. The equipment variable costs are presented in table 6.4-3 and are referenced by engine power category. For the 76hp example here, the estimated equipment variable costs are $55.

Having estimated the engine and equipment fixed and variable costs it is possible to estimate the total new product costs (excluding operating costs changes) by simply totaling the fixed and variable costs estimate here. The resulting total is $1670 ($143 + $1472 + $55, note that rounding may result in slightly different results). Typically we have presented these total cost estimates to the nearest ten dollars.

Chapter 6 References

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CHAPTER 5: Fuel Standard Feasibility

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CHAPTER 5: Fuel Standard Feasibility

In this chapter, we present the methodology used to develop the costs which would result from the proposed fuel program, as well as the projected costs themselves. In Section 5.1, we estimate the volumes of diesel fuel which would be affected by the 500 and 15 ppm sulfur caps in various phases of the proposed fuel program. In Section 5.2, we evaluate a wide variety of distillate desulfurization technologies which refiners could potentially use to meet 500 and 15 ppm sulfur caps. In Section 5.3, we formally assess the technical feasibility of the 500 ppm sulfur cap in 2007, including the sufficiency of the leadtime provided refiners. In Section 5.4, we assess the feasibility of distributing the 500 ppm sulfur fuel which would be required in 2007. In Section 5.5, we formally assess the technical feasibility of the 15 ppm sulfur cap in 2010, including the sufficiency of the leadtime provided refiners. In Section 5.6, we assess the feasibility of distributing the 15 ppm sulfur fuels which would be required in 2010. Finally, in Section 7.6, we project the possible impacts of the proposal on diesel fuel prices.

5.1 Blendstock Properties of Non-Highway Diesel Fuel

5.1.1 Blendstocks Comprising Non-highway Diesel Fuel and their Sulfur Levels

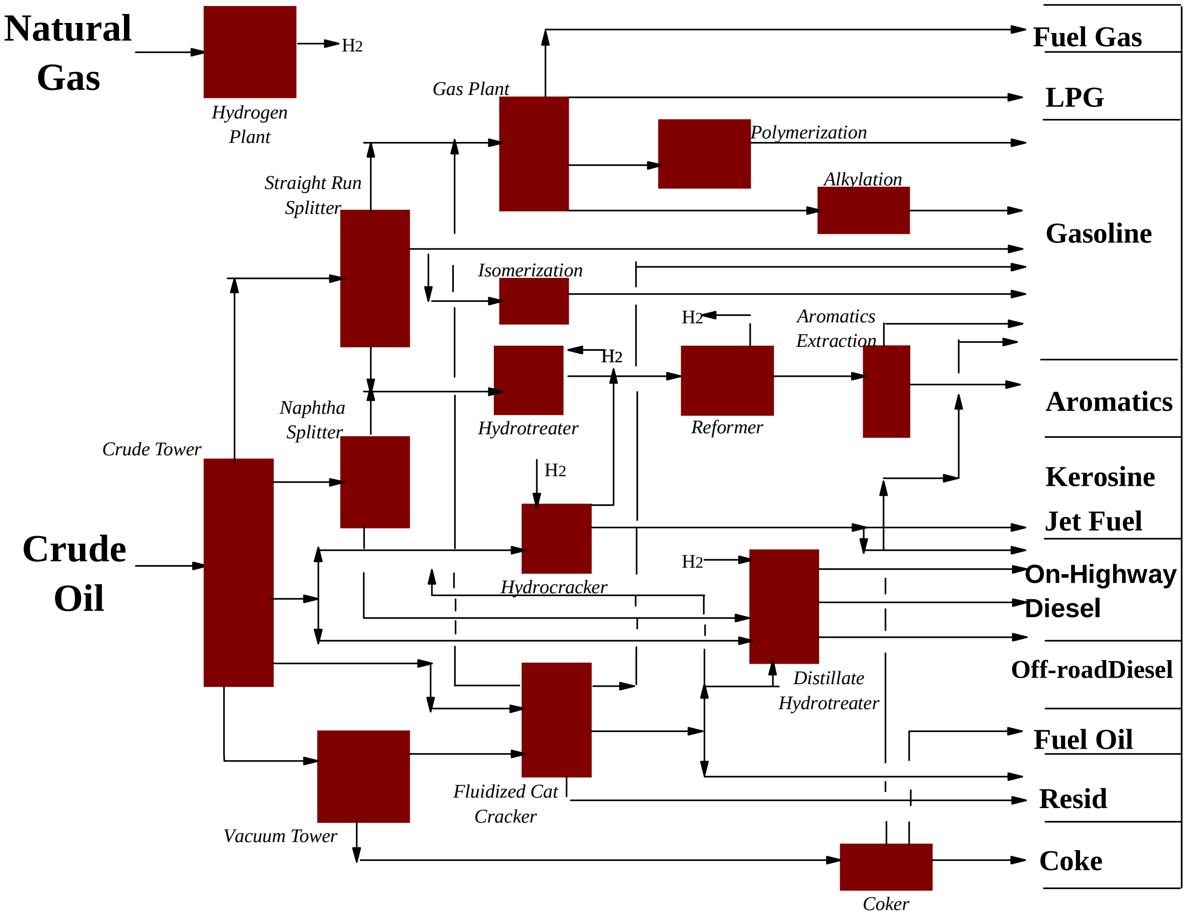
The primary sources of sulfur in diesel fuel are the sulfur-containing compounds which occur naturally in crude oil.[A] Depending on the source, crude oil contains anywhere from fractions of a percent of sulfur, such as less than 0.05 weight percent (500 ppm) to as much as several weight percent.[1] The average amount of sulfur in crude oil refined in the U.S. is about one weight percent.[2] Most of the sulfur in crude oil is in the heaviest boiling fractions. Since most of the refinery blend stocks that are used to manufacture diesel fuel come from the heavier boiling components of crude oil, they contain substantial amounts of sulfur.

The distillate[B] produced by a given refinery is composed of one or more blend stocks from crude oil fractionation and conversion units at the refinery. Refinery configuration and equipment, and the types and relative volumes of products manufactured (the product slate) can significantly affect the sulfur content of diesel fuel. The diagram on the following page illustrates the configuration and equipment used at a typical complex refinery in the U.S.

[A] Additives that contain sulfur are sometimes intentionally added to diesel fuel. For a discussion how the addition of these additives will be affected under this program, see Section IV.D.5.

[B] Distillate refers to a broad category of fuels falling into a specific boiling range. Distillate fuels have a heavier molecular weight and therefore boil at higher temperatures than gasoline. Distillate includes diesel fuel, kerosene and home heating oil. For the purposes of this discussion, we will focus on number 2 distillate which comprises the majority of diesel fuel and heating oil.

Figure 5.1-1
Diagram of a Typical Complex Refinery



Refineries differ from the model in the preceding diagram depending on the characteristics of the crude oils refined, and their product slate. For example:

- Refineries that process lighter crude oils are less likely to have coker and hydrocracker units.

- Refinery streams that can be used to manufacture diesel fuel can also be used in the manufacture of heating oil, kerosene and jet fuel. Much of the distillate product from the hydrocracker is often blended into jet fuel rather than diesel fuel and current highway regulations generally require that a refinery have a hydrotreater which usually would not be necessary if the refinery produced only heating oil.

On an aggregate basis, most of the distillate manufactured in the U.S. comes from the crude fractionation tower (called straight run or SR). Most of the remainder comes from the fluid catalytic cracker (FCC) conversion unit (called light cycle oil or LCO). The remaining small fraction of diesel fuel volume comes from a coker conversion unit or other units which crack heavy compounds such as a visbreaker or steam cracker (called other cracked stocks in this document), or from the hydrocracker conversion unit (called hydrocrackate).

To comply with the current federal regulatory requirement on the sulfur content of highway diesel fuel (500 ppm cap), the blendstock streams from these process units are typically further processed to reduce their sulfur content. Desulfurization of highway diesel blendstocks is currently accomplished in fixed-bed hydrotreaters that operate at moderate pressures (500-800+ psi)[3]. Nearly all of the low-sulfur diesel blendstocks come from such hydrotreaters. However, a small amount of low-sulfur diesel also comes from hydrocrackers operating at pressures of 500 - 3000 psi, although most operate at 1500 - 3000 psi, which naturally produces distillate fuel with sulfur levels of about 100 ppm.

To comply with applicable sulfur standards, which range from 2000-5000 ppm, or the 40 cetane standard for non-highway diesel fuel, some of the distillate blendstocks used to produce non-highway diesel fuel and heating oil are hydrotreated. A significant amount of hydrocracked distillate is also blended into non-highway diesel fuel and heating oil. As will be discussed in Chapter 7, the use of hydrotreated blendstocks in non-highway diesel fuel has important implications for the cost of desulfurizing NRLM diesel fuel.

The distillate blendstocks used to produce non-highway diesel fuel and their sulfur content vary considerably from refinery to refinery. A survey conducted by the American Petroleum Institute (API) and National Petroleum Refiners Association (NPRA) in 1996 examined the typical blendstock properties for the U.S. highway and the non-highway diesel pools.[4] The results of this survey for the non-highway distillate pool are contained in Table 5.1-1.

Table 5.1-1
Average Composition and Sulfur Content of the Non-highway Distillate Pool Outside of California in 1996 [5]

Type of Distillate Stream	Diesel Blendstock	Percentage	Sulfur Content (ppm)
Unhydrotreated	Straight Run	45	2274
	Light Cycle Oil (LCO)	12	3493
	Coker Gas Oil	1	2345
	Unhydrotreated Subtotal	58	-
Hydrotreated	Hydrotreated Straight Run	18	353
	Hydrotreated LCO	10	1139
	Hydrotreated Coker Gas Oil	4	270
	Hydrocrackate	10	115
	Hydrotreated Subtotal	42	-
	Total	100	-

As shown in Table 5.1-1, approximately 42 percent of all blendstocks used to manufacture non-highway distillate outside of California are hydrotreated to reduce their sulfur content. This includes hydrocrackate (10 percent of the non-highway distillate pool), which is desulfurized to a substantial extent as a necessary element of the hydrocracking process and is not further processed in a hydrotreater. Table 5.1-1 also shows that approximately 58 percent of non-highway distillate comes from nonhydrotreated blendstocks. As expected, the sulfur levels of the hydrotreated blendstocks are lower than the nonhydrotreated distillate blendstocks.

5.1.2 Current Levels of Other Fuel Parameters in Non-highway Distillate

It is useful to review other qualities of high sulfur distillate, as well as sulfur content, for a couple of reasons. First, some of the desulfurization technologies affect these other fuel properties. Second, as will be discussed further below, some sulfur compounds are more difficult to treat than others. Refiners could potentially try to shift these more difficult compounds to fuels which face less stringent sulfur standards. Their ability to do this depends in part on the effect of such shifts on non-sulfur properties and whether or not these other properties still meet industry specifications. Thus, it is helpful to evaluate the degree to which current non-highway distillate fuels meet or exceed their applicable industry standards.

Data on the current distillation characteristics, API gravity, pour point, natural cetane level, and aromatics content of diesel fuel blendstocks are contained in the Table 5.1-2.

Table 5.1-2
Average Non-highway Distillate Fuel Property Levels by Geographic Area[6] [7]
(Data from 1997 API/NPRA Survey unless specified)

Fuel Parameter		PADD 1	PADD 2	PADD 3	PADD 4	PADD 5 (CA Excluded)	U.S. (CA Excluded)	CA
API Gravity		32.6	34.1	32.6	35.6	33.8	32.8	30.8
Cetane Number[a]		N/A	N/A	N/A	N/A	N/A	47	N/A
Pour Point (°F) [additized]		-6	-8	0	6	12	-1	4
Pour Point Depressant Additive (ppmw)		0	71	0	13	0	18	0
Distillation (°F)	T10	434	425	418	411	466	419	498
	T30	492	476	457	443	517	464	
	T50	517	508	502	499	542	503	556
	T70	545	558	536	522	570	539	
	T90	613	604	598	591	616	595	620

[a] From 1997 NIPER/TRW survey data, U.S. average includes California. N/A means not available.

The American Society for Testing Materials (ASTM) has established consensus standards which apply to #2 non-highway diesel fuel, as well as for #2 distillate fuel (e.g., heating oil).[8] The specifications which are most relevant to desulfurization are summarized in Table 5.1-3.

Table 5.1-3
ASTM Specifications which Apply to Non-Highway Distillate Fuels

	#2 Diesel Fuel (Non-highway)	#2 Fuel Oil/Heating Oil	#2 Marine Distillate (DMA)
T-90 Min °F	540	540	—
T-90 Max °F	640	640	—
Density max (g/cm^3) (API Gravity min)	None	0.876 (30.0)	0.890 (27.5)
Pour Point max °F		21.2	21.2
Cloud Point °F	46 to -0.4		
Sulfur max (ppm)	5000	5000	
Cetane Number min	40		40

Comparing Tables 5.1-2 and 5.1-3 shows that the average properties of current non-highway distillate are within the specifications, and for some properties, well within specifications. For example, except for California, the T90 of current non-highway diesel fuel is 25-40°F below the maximum allowed. The average cetane number of all non-highway distillate is well above the minimum of 40. Finally the pour point is well below the maximum allowed for fuel oil/heating oil and marine distillate fuel. One exception is that the API gravity of non-highway distillate fuel in PADDs 1 and 3, which includes the heating oil used in the Northeast, is just above the minimum.

While refiners might try to perform such shifts in blendstocks between fuels, it should be noted that we did not assume that refineries would be shifting blendstocks between various distillate fuels in order to reduce the compliance costs associated with the proposed NRLM diesel fuel sulfur standards. Instead, we projected the use of desulfurization techniques which would be sufficient to meet the proposed sulfur standards without shifting more difficult to treat sulfur compounds to other fuels. This approach appeared reasonable given that we were evaluating the potential of over 100 refineries which currently produce non-highway distillate fuel to reduce NRLM diesel fuel sulfur. The ability to shift blendstocks between fuels to reduce costs would be very refinery specific and difficult to estimate on average across a wide range of refineries. Also, two primary types of shifts are possible and both have limits. One approach would be to shift the heaviest portion of selected blendstocks such as LCO to the bunker or residual fuel pool, avoiding the need to desulfurize this material. However, the market for these heavy fuels is limited and on a national basis, this approach is generally not economically feasible. The other approach would be to shift these difficult to treat streams and portions of streams to heating oil, which must meet less stringent sulfur standards. This would likely require the addition of additional product tankage and require more refineries to produce lower sulfur NRLM diesel fuel. The material being shifted to heating oil could still require additional desulfurization to ensure that ASTM and state standards were still being met. Thus, there would be a cost trade-off, not just a cost reduction. Again, given the national scale of this analysis, we decided to avoid the projection of such shifts and limit our analysis to the desulfurization of current non-highway diesel fuel blendstocks.

5.2 Evaluation of Diesel Fuel Desulfurization Technology

5.2.1 Introduction to Diesel Fuel Sulfur Control

As mentioned in Section 5.1, the sulfur in diesel fuel comes from the crude oil processed by the refinery. One way to reduce the amount of sulfur in diesel fuel, therefore, is to process a crude oil that is lower in sulfur. Some refiners already do this. Others could switch to low or at least lower sulfur crude oils. However, there is limited capability worldwide to produce low sulfur crude oil. While new oil fields producing light, sweet crude oil are still being discovered, most of the new crude oil production being brought on-line is heavier, more sour (i.e., higher sulfur) crude oils. The incentive to use low sulfur crude oils has existed for some time and low sulfur crude oils have traditionally commanded a premium price relative to higher sulfur crude oils. While a few refiners with access to lower sulfur crude oil could potentially reduce their diesel sulfur levels in this way, it is not feasible for most, let alone all U.S. refiners to switch to low sulfur crude oils to meet a tighter diesel fuel sulfur standard. In addition, while helpful, a simple change to a low sulfur crude oil may fall short of compliance with the 500 ppm sulfur cap standard, and certainly fall short of the 15 ppm sulfur cap standard. Thus, changing to a sweeter crude oil was not considered to be viable for complying with the proposed nonroad, locomotive and marine diesel sulfur standards.

Another method to reduce diesel fuel sulfur, but much more significantly, is to chemically remove sulfur from the hydrocarbon compounds which comprise diesel fuel. This is usually accomplished through catalyzed reaction with hydrogen at moderate to high temperature and pressure. A couple of specific examples of this process are hydrotreating and hydrocracking. A modified version of hydrotreating which operates solely in the liquid state was announced recently. Another process was announced recently which uses a moving bed catalyst to both remove and adsorb the sulfur using hydrogen at moderate temperature and pressure. There are other low temperature and pressure processes being developed which don't rely on hydrotreating, such as biodesulfurization, and chemical oxidation. Sulfur can be removed via these processes up front in the refinery, such as from crude oil, before being processed in the refinery into diesel fuel. Or, sulfur can be removed from those refinery streams which are to be blended directly into diesel fuel. Finally, another method to moderately reduce diesel fuel sulfur is to shift sulfur-containing hydrocarbon compounds to other fuels produced by the refinery.

After careful review of all these approaches, we expect that the sulfur reduction which would be required by the proposed 2007 500 ppm sulfur cap standard would occur through chemical removal via conventional hydrotreating. For complying with the proposed 15 ppm cap standard for nonroad diesel fuel which would be required in 2010, we expect that it would be met primarily through adsorption and liquid phase hydrotreating, which are emerging advanced desulfurization technologies. Thus, this section will begin with a relatively detailed discussion of the capabilities of these various processes. Refiners may use the other methods to obtain cost effective sulfur reductions which will complement the primary sulfur reduction achieved via hydrotreating and adsorption. These other methods, such as FCC feed hydrotreating, biodesulfurization, and chemical oxidation will be discussed following the primary discussion of distillate hydrotreating, liquid phase hydrotreating and adsorption. Another means for aiding the desulfurization of diesel fuel, particularly to comply with the 15 ppm cap standard, is undercutting which removes the most difficult to treat sulfur compounds. Since undercutting can help ease the task of complying with the 15 ppm cap standard for any of the desulfurization technologies, we provide a discussion of undercutting below in this subsection.

5.2.2 Conventional Hydrotreating

Hydrotreating generally combines hydrogen with a hydrocarbon stream at high temperature and pressure in the presence of a catalyst. Refineries currently employ a wide range of these processes for a number of purposes. For example, naphtha (gasoline like material which itself does not meet gasoline specifications, such as octane level) being fed to the refinery reformer is always hydrotreated to remove nearly all sulfur, nitrogen and metal contaminants which would deactivate the noble metal catalyst used in the reforming process. Similarly, feed to the FCC unit is often hydrotreated to remove most of the sulfur, nitrogen and metal contaminants in order to improve the yield and quality of high value products, such as gasoline and distillate, from the FCC unit. Refineries currently producing highway diesel fuel which must meet a 500 ppm cap standard hydrotreat their distillate to remove much of the sulfur present and to improve the cetane. That same unit or another hydrotreating unit in the refinery also hydrotreats some of the refinery streams used to blend up nonhighway distillate. EPA expects that nearly all refiners will hydrotreat the naphtha produced by the FCC unit to remove most of the sulfur present to comply with the Tier 2 gasoline sulfur standards.[9]

If the temperature or pressure is increased sufficiently and if a noble metal catalyst is used, hydrotreating can more dramatically affect the chemical nature of the hydrocarbons, as well as remove contaminants. For example, through a process called hydrocracking, smaller, lighter molecules are created by splitting larger, heavier molecules. In the process, nearly all of the contaminants are removed and olefins and aromatics are saturated into paraffins and naphthenes. Outside the U.S., this process is commonly used to produce distillate from heavier, less marketable refinery streams. In the U.S. the hydrocracker is most often used to produce gasoline from poor quality distillate, such as LCO from the FCC unit.

A few refineries also currently hydrotreat their distillate more severely than is typical, but not as severely as hydrocracking. Their intent is to remove the sulfur, nitrogen and metallic contaminants and to also saturate most of the aromatics present. This is done primarily in Europe to meet very stringent specifications for both sulfur and aromatics applicable to certain diesel fuels and encouraged by reduced excise taxes. This severe hydrotreating process is also used in the U.S. to “upgrade” petroleum streams which are otherwise too heavy or too low in quality to be blended into the diesel pool, by cracking some of the material to lower molecular weight compounds and saturating some of the aromatics to meet the distillation and cetane requirements. A different catalyst which encourages aromatic saturation is used in lieu of one that simply encourages contaminant removal.

To meet the 500 ppm and the 15 ppm diesel fuel sulfur cap standards, EPA expects refiners to focus as much as possible on sulfur removal. Other contaminants, such as nitrogen and metals, are already sufficiently removed by existing refinery processes. While saturation of aromatics generally improves cetane, the cetane numbers of todays nonroad, locomotive and marine diesel fuels are already sufficient to comply with the ASTM standards which apply. Thus, refiners would want to avoid saturating aromatics to avoid the additional cost of increased hydrogen consumption. Consequently, we anticipate refiners will choose desulfurization processes that minimize the amount of aromatics saturation. Current diesel fuel already meets all applicable specifications, and hydrotreating to remove sulfur should not degrade quality, except possibly lubricity, as discussed in Section C. Thus, with this one exception, there should be no need to improve diesel fuel quality as a direct result of this new diesel sulfur standard. Should a refiner choose to do so, it would be to improve profitability,[C] and not related to meeting the 15 ppm sulfur cap standard.

5.2.2.1 Fundamentals of Distillate Hydrotreating

Essentially all distillate hydrotreater designs follow the same broad format. Liquid distillate fuel is heated to temperatures of 300-380°C, pumped to pressures of 500-700 psia, mixed with hydrogen, and passed over a catalyst. Hydrogen reacts with sulfur and nitrogen atoms contained in the hydrocarbon molecules, forming hydrogen sulfide and ammonia. The resulting vapor is then separated from the desulfurized distillate. The desulfurized distillate is usually simply mixed with other distillate streams in the refinery to produce diesel fuel and heating oil.

The vapor still contains a lot of valuable hydrogen, because the reaction requires the use of a significant amount of excess hydrogen to operate efficiently and practically. However, the vapor also contains a significant amount of hydrogen sulfide and ammonia, which inhibit the desulfurization and denitrogenation reactions and must be removed from the system. Thus, the hydrogen leaving the reactor is usually mixed with fresh hydrogen and recycled to the front of the reactor for reaction with fresh distillate feed. Itself, this would cause a build up of hydrogen sulfide and ammonia in the system, since it would have no way to leave the system. In some cases, the hydrogen sulfide and ammonia are chemically scrubbed from the hydrogen recycle stream. In other cases, a portion of the recycle stream is simply purged from the system as a mixture of hydrogen, hydrogen sulfide and ammonia. The latter is less efficient since it leads to

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[C] Refiners can choose to "upgrade" heavy refinery streams which do not meet the cetane and distillation requirements for highway diesel fuel. The process for doing so is also called ring opening, since one or more of the aromatic rings of heavy, aromatic molecules are opened up, improving the value of the stream. Upgrading the heavy refinery streams to highway diesel fuel improves the stream's market price by 10 - 30 c/gal.

higher levels of hydrogen sulfide and ammonia in the reactor, but it avoids the cost of building and operating a scrubber.

Desulfurization processes in use today in the U.S. generally use only one reactor, due to the need to only desulfurize diesel fuel to 500 ppm or slightly lower. However, a second reactor can be used, particularly to meet lower sulfur levels. Instead of liquid distillate fuel going to the diesel fuel/heating oil pool after the first reactor, it would be stripped of hydrogen sulfide and ammonia and mixed with fresh hydrogen and sent to the second reactor.

Traditional reactors are cocurrent in nature. The hydrogen is mixed together with the distillate at the entrance to the reactor and flow through the reactor together. Because the reaction is exothermic, heat must be removed periodically. This is sometimes done through the introduction of fresh hydrogen and distillate fuel in the middle of the reactor. The advantage of cocurrent design is practical, it eases the control of gas-liquid mixing and contact with the catalyst. The disadvantage is that the concentration of hydrogen is the highest at the front of the reactor where the easiest to remove sulfur is and lowest at the outlet where the hardest to remove sulfur is. The opposite is true for the concentration of hydrogen sulfide. This increases the difficulty of achieving extremely low sulfur levels due to the low hydrogen concentration and high hydrogen sulfide concentration at the end of the reactor.

The normal solution to this problem is to design a counter-current reactor, where the fresh hydrogen is introduced at one end of the reactor and the liquid distillate at the other end. Here, the hydrogen concentration is highest (and the hydrogen sulfide concentration is lowest) where the reactor is trying to desulfurize the most difficult (sterically hindered) compounds. The difficulty of counter-current designs in the case of distillate hydrotreating is vapor-liquid contact and the prevention of hot spots within the reactor. The SynAlliance (Criterion Catalyst Corp., and Shell Oil Co.) has patented a counter-current reactor design called SynTechnology. With this technology, in a single reactor design, the initial portion of the reactor will follow a co-current design, while the last portion of the reactor will be counter-current. In a two reactor design, the first reactor could be co-current, while the second reactor could be counter-current.

ABB Lummus estimates that the counter-current design can reduce the catalyst volume needed to achieve 97 percent desulfurization by 16 percent relative to a co-current design.[10] The impact of the counter-current design is even more significant when aromatics control (or cetane improvement) is desired in addition to sulfur control.

Sulfur containing compounds in distillate can be classified according to the ease with which they are desulfurized. Sulfur contained in paraffins or aromatics with a single aromatic ring are relatively easy to desulfurize. These molecules are sufficiently flexible so that the sulfur atom is in a geometric position where it can make physical contact with the surface of the catalyst. The more difficult compounds are contained in aromatics consisting of two aromatic rings, particularly dibenzothiophenes. Dibenzothiophene contains two benzene rings which are connected by a carbon-carbon bond and two carbon-sulfur bonds (both benzene rings are bonded to the same sulfur atom). This compound is essentially flat in nature and the carbon atoms bound to the sulfur atom hinder the approach of the sulfur atom to the catalyst surface. Despite this, today's catalysts are very effective in desulfurizing dibenzothiophenes, as long as only hydrogen is attached to the carbon atoms bound directly to the sulfur atom.

However, distillate fuel can contain dibenzothiophenes which have methyl or ethyl groups bound to the carbon atoms which are in turn bound to the sulfur atom. These extra methyl or ethyl groups further hinder the approach of the sulfur atom to the catalyst surface. Dibenzothiophenes with such methyl or ethyl groups are commonly referred to as being sterically hindered. An example of a dibenzothiophene with a single methyl or ethyl group next to the sulfur atom is 4-methyl dibenzothiophene. An example of a dibenzothiophene with two methyl or ethyl groups next to the sulfur atom is 4,6-dimethyl dibenzothiophene. In 4,6-dimethyl dibenzothiophene, and similar compounds, the presence of a methyl group on either side of the sulfur atom makes it very difficult for the sulfur atom to react with the catalyst surface to assist the hydrogenation of the sulfur atom.

Most straight run distillates contain relatively low levels of these sterically hindered compounds. LCO contains the greatest concentration of sterically hindered compounds, while other cracked distillate streams from the coker and the visbreaker contain levels of sterically hindered compounds in concentrations between straight run and LCO. Thus, LCO is generally more difficult to desulfurize than coker distillate which is in turn more difficult to treat than straight run distillate.[11] In addition, cracked stocks, particularly LCO, have a greater tendency to form coke on the catalyst, which deactivates the catalyst and requires its regeneration or replacement.

The greater presence of sterically hindered compounds in LCO is related to two fundamental factors. First, LCO contains much higher concentrations of aromatics than typical SRLGO.[12] All sterically hindered compounds are aromatics. Second, the chemical equilibria existing in cracking reactions favors the production of sterically hindered dibenzothiophenes over unsubstituted dibenzothiophenes. For example, in LCO, methyl substituted aromatics are twice as prevalent as unsubstituted aromatics. Di-methyl aromatics are twice as prevalent as methyl aromatics, or four times more prevalent as unsubstituted aromatics. Generally, desulfurizing 4-methyl dibenzothiophene using conventional desulfurization is 6 times slower than desulfurizing similar non-sterically hindered molecules, while desulfurizing 4,6-dimethyl dibenzothiophene using conventional desulfurization is 30 times slower. Slower reactions mean that either the volume of the reactor must be that much larger, or that the reaction must be somehow speeded up. The latter implies either a more active catalyst, higher temperature, or higher pressure. These alternatives will be discussed later below.

Because moderate sulfur reduction is often all that is required in current distillate hydrotreating, catalysts have been developed which focus almost exclusively on sulfur and other contaminant removal, such as nitrogen and metals. The most commonly used desulfurization catalyst consists of a mixture of cobalt and molybdenum (Co/Mo). These catalysts interact primarily with the sulfur atom and encourage the reaction of sulfur with hydrogen.

Other catalysts have been developed which encourage the saturation (hydrogenation) of the aromatic rings. As mentioned above, this generally improves the quality of the diesel fuel produced from this distillate. These catalysts also indirectly encourage the removal of sulfur from sterically hindered compounds by eliminating one or both of the aromatic rings contained in dibenzothiophene. Without one or both of the rings, the molecule is much more flexible and the sulfur atom can approach the catalyst surface much more easily. Thus, the desulfurization rate of sterically hindered compounds is greatly increased through the hydrogenation route. The most commonly used hydrogenation/desulfurization catalyst consists of a mixture of nickel and molybdenum (Ni/Mo).

There are a number important issues which should be highlighted about using the hydrogenation pathway for desulfurization. As pointed out above, one or both of the aromatics rings are being saturated which significantly increases the consumption of hydrogen. It is important that one of the aromatic rings of a polyaromatic compound is saturated, as this is the facilitating step which results in the desulfurization of a sterically hindered compound. If the mono aromatics compounds are also saturated, there would only be a modest improvement in the desulfurization reaction rate of the sterically hindered compounds, however, at a large hydrogen cost. In addition, certain diesel fuel qualities, such as cetane, would improve significantly as more of the aromatic compounds are saturated. However, the vendors of diesel desulfurization technology explained to us that if cetane improvement is not a goal, then the most cost effective path to desulfurize the sterically hindered compounds is to saturate the polyaromatic compounds to monoaromatic compounds, but not to saturate the monoaromatic compounds. The vendors tell us that because the concentration of the monoaromatic compounds is at equilibrium conditions within the reactor, the monoaromatic compounds are being both saturated and unsaturated, which helps to enable the desulfurization of these compounds. It also means that the concentration can be controlled temperature and pressure.

The vendors also point out a number of reasons why the cycle length of the catalysts which catalyze hydrogenation reactions, which would likely occur in a second stage, is longer than the first stage desulfurization catalyst. First, the temperature at which the hydrogenation reactions occur to saturate the polyaromatic compounds to monoaromatic compounds, but not to saturate the monaromatic compounds is significantly lower than the temperature of the first stage. The lower temperature avoids color change problems and reduces the amount of coke formation on the hydrogenation catalyst. Furthermore, since the first stage has somewhat “cleaned” the diesel fuel of contaminants such as sulfur, nitrogen and metals, the catalyst in this second hydrogenation stage is not degraded as quickly. Because the second stage would have a cycle length which is as long as or longer as the first stage, adding the second stage is not expected to shorten the cycle length of the current distillate hydrotreater.

If refiners are “upgrading” their diesel fuel by converting heavy, high aromatic, low cetane, stocks to 15 ppm diesel fuel sulfur standard, they are intentionally reacting a lot of hydrogen with the diesel fuel. The hydrogen reactions with the diesel fuel saturates many or most of the aromatics, increases cetane number and greatly eases the reduction of sulfur. The lower concentration of aromatics and improved cetane of the upgraded feedstock would then allow the product to be sold as highway diesel fuel. The much higher sales price of the highway diesel fuel compared to the lower value of the feedstock justifies the much larger consumption in hydrogen and the cost of a larger reactor.

Up to a certain level of sulfur removal, the CoMo catalyst is generally preferred. It is more active with respect to desulfurizing non-sterically hindered compounds, which comprise the bulk of the sulfur in distillate, straight run or cracked. Below that level, the need to desulfurize sterically hindered compounds leads to greater interest in NiMo catalysts. Acreon Catalysts had indicated that NiMo are preferred for deep desulfurization around 15 ppm due to this catalyst's ability to saturate aromatic rings and make the sulfur atom more accessible to the catalyst. On the other hand, Haldor-Topsoe has performed studies which indicate that CoMo catalysts may still have an advantage over NiMo catalysts, even at sulfur levels below 50 ppm.[13]

Two-stage processes may also be preferable to achieve ultra-low sulfur levels. Both stages could emphasize desulfurization or desulfurization could be emphasized in the first stage and hydrogenation/desulfurization emphasized in the second stage. In addition to this advantage, the main advantage of two stages lies in the removal of hydrogen sulfide from the gas phase after the first stage. Hydrogen sulfide strongly inhibits desulfurization reactions, as will be discussed further in the next section. It can also recombine with non-sulfur containing hydrocarbon compounds at the end of the reactor or even in subsequent piping, essentially adding sulfur to the desulfurized distillate. Removing hydrogen sulfide after the first stage reduces the hydrogen sulfide concentration at the end of the second stage by roughly two orders of magnitude, dramatically reducing both inhibition and recombination.

In one study, Haldor-Topsoe analyzed a specific desulfurized 50/50 blend of SRGO and LCO at 150 ppm sulfur and found that essentially all of the sulfur is contained in sterically hindered compounds.[14] This feed contains more LCO than would be processed in the typical refinery. A refinery processing less LCO would presumably reach the point where the sulfur compounds were dominated by sterically hindered compounds at a lower sulfur level. They also compared the performance of CoMo and NiMo catalysts on a SRLGO feed at the same space velocity. The NiMo catalyst performed more poorly than the CoMo catalyst above 200 ppm sulfur, and better below that level. This implies that much of the sulfur left at 200 ppm (and even above this level) was sterically hindered. These two studies indicate that the amount of sterically hindered compounds can exceed the 15 ppm sulfur cap by a substantial margin.

In addition to NiMo catalysts, precious metal catalysts are also very effective in desulfurizing sterically hindered compounds. An example of a precious metal catalyst is the ASAT catalyst developed by United Catalysts and Sud-Chemie AG, which uses both platinum and palladium.[15] They are most commonly used to more severely dearomatize distillate and increase cetane by opening up the aromatic rings, a process called ring opening.

5.2.2.2 Meeting a 15 ppm Cap with Distillate Hydrotreating

Using distillate hydrotreating to meet a 15 ppm sulfur cap on diesel fuel has been commercially demonstrated, as will be discussed below. Thus, meeting the 15 ppm cap is quite feasible using current refining technology. Assessing the most reliable and economic means of doing so is more complicated. Refiners already hydrotreat their highway diesel fuel to meet a 500 ppm sulfur cap. These hydrotreaters use a variety of catalysts and have a range of excess capacity. Thus, refiners are not all starting from the same place. Many refiners would also be producing locomotive and marine diesel fuel which would have to meet a 500 ppm cap and heating oil which only needs to meet a 5000 ppm cap, which would have less stringent sulfur requirements and could, for example, provide a place to blend the sterically hindered sulfur-containing compounds. Finally, the amount of cracked stocks that a refiner processes into diesel fuel varies widely. Those with a greater fraction of LCO would face a more difficult task of complying with a 15 ppm cap, than those processing primarily straight run distillate.

To understand the types of modifications which can be made to current distillate hydrotreating to improve its performance, it is useful to better understand the quantitative relationships between the various physical and chemical parameters involved in hydrotreating. Haldor-Topsoe has developed the following algebraic expression to describe the rate of desulfurization via both direct desulfurization and hydrogenation/desulfurization.

$$\begin{array}{l} \text{Rate of} \\ \text{Desulfurization} \\ \text{Per Catalyst} \\ \text{Surface Area} \end{array} = \frac{k \times C_s^n \times P_{H2}^a}{(1 + K_{H2S} \times P_{H2S})} + \frac{k \times C_s^m \times P_{H2}^b}{(1 + K_F \times C_F)}$$

Where:

k, K_{H2S} and K_F are various rate constants, which only vary with temperature.
C_s is the concentration of sulfur in the distillate.
P_{H2} and P_{H2S} are the partial pressures of hydrogen and hydrogen sulfide in the vapor phase.
$K_F \times C_F$ is the total inhibition due to hydrogen sulfide, ammonia, and aromatics n, m, a, and b are various constant exponents.

The first term represents the rate of direct desulfurization, such as that catalyzed by CoMo. This reaction rate increased by increasing the partial pressure of hydrogen. However, it is inhibited by increasing concentrations of hydrogen sulfide, which competes with the distillate for sites on the catalyst surface.

The second term represents the rate of desulfurization via hydrogenation of the aromatic ring next to the sulfur atom. This rate of desulfurization also increases with higher hydrogen partial pressure. However, this reaction is inhibited by hydrogen sulfide, ammonia, and aromatics. This inhibition by aromatics leads to the presence of a thermodynamic equilibrium condition which can prevent the complete saturation of aromatics. Also, this inhibition makes it more difficult to desulfurize cracked stocks, which contain high concentrations of both sterically hindered sulfur compounds and aromatics. While the literature generally expresses a preference for NiMo catalysts for desulfurizing cracked stocks, Haldor-Topsoe has found situations where this aromatics inhibition leads them to favor CoMo catalysts even for desulfurizing feeds with a high concentration of sterically hindered compounds.

These relationships essentially identify the types of changes which could be made to improve the performance of current distillate hydrotreaters. First, a more active catalyst can be used. This increases the "k" terms in the above equations. Second, temperature can be increased, which also increases the "k" terms in the above equations. Third, improvements can often be made in vapor-liquid contact, which effectively increases the surface area of the catalyst. Fourth, hydrogen purity can be increased. This increases the hydrogen concentration, which the P_{H2} term in the two numerator terms of the equation. Fifth, the concentration of hydrogen sulfide in the recycle stream can be removed by scrubbing. This decreases the P_{H2S} and C_F terms in the two denominator terms of the equation. Finally, more volume of catalyst can be used, which increases the surface area proportionally.

Regarding catalysts, at least two firms have announced the development of improved catalysts since the time that most distillate hydrotreaters were built in the U.S. to meet the 1993 500 ppm sulfur cap: Akzo Nobel / Nippon Ketjen Catalysts (Akzo Nobel) and Haldor-Topsoe. Akzo Nobel currently markets four CoMo desulfurization catalysts: KF 752, KF 756 and KF 757 which have been available for several years, and KF 848, which was announced in year 2000.[16] KF 752 can be considered to be typical of an Akzo Nobel catalyst of the 1992-93 timeframe, while KF 756 and 757 catalysts represent improvements. Akzo Nobel estimates that under typical conditions (e.g., 500 ppm sulfur), KF 756 is 25 percent more active than KF 752, while KF 757 is more than 50 percent more active than KF 752 and 30 percent more active than KF 756.[17] However, under more severe conditions (e.g., <50 ppm sulfur), KF 757 is 35-75 percent more active than KF 756. KF 848 is 15 - 50 percent more active than KF 757. Commercial experience exists for both advanced catalysts. KF 756 is widely used in Europe (20 percent of all distillate hydrotreaters operating on January 1, 1998), while KF 757 has been used in at least three hydrotreaters commercially. KF 757 and KF 842 utilizes what Akzo Nobel calls STARS technology, Super Type II Active Reaction Sites. Type II refers to a specific kind of catalyst site which is particular good at removing sulfur from sterically hindered compounds.

In terms of sulfur removal, Akzo Nobel projects that a desulfurization unit producing 500 ppm sulfur with KF 752, would produce 405, 270 and 160ppm sulfur with KF 756, KF757, and KF 842, respectively.

In 2001, Akzo Nobel announced a new highly active catalyst named Nebula which offers a different way in which coatings are used for catalysts. A typical catalyst is composed of two parts: an active coating which contains metals and a generally inactive substrate. For Nebula, Akzo Nobel concentrated the metal coatings and omitted the substrate. Because of the very high metals content, Nebula costs several times more than conventional catalysts. The higher activity of the Nebula catalyst leads to an increased tendency for coking, which must be countered by using a high hydrogen partial pressure, resulting in a higher hydrogen consumption. (The hydrogen consumption is higher because a higher percentage of the aromatics are saturated to nonaromatic compounds.) According to Akzo Nobel, a refiner may be able to meet the 15 ppm sulfur standard by simply replacing its existing catalyst with Nebula and providing significantly more hydrogen (which may possibly require the addition of a hydrogen plant). Nebula is a new catalyst that could avoid some or much of the capital investment that would otherwise be required for meeting the 15 ppm sulfur standard.

Haldor-Topsoe has also developed a more active catalyst. Its TK-554 catalyst is analogous to Akzo Nobel's KF 756 catalyst, while its newer, more active catalyst is termed TK-574. For example, in pilot plant studies, under conditions where TK-554 produces 400 ppm sulfur in SRLGO, TK 574 will produce 280 ppm. Under more severe conditions, TK-554 will produce 60 ppm, while TK 574 will produce 30 ppm. Similar benefits are found with a mixture of straight run and cracked stocks.

UOP projects a similar reduction in sulfur due to an improved catalyst. They estimate that a hydrotreater producing 500 ppm sulfur distillate today (20% LCO, 10% light coker gas oil) could produce 280 ppm sulfur distillate with a 50 percent more active catalyst.[18]

Over the last four years, Criterion Catalyst Company announced two new lines of catalysts. One is called Century, and the other is called Centinel.[19] These two lines of catalysts are reported to be 45 - 70 percent and 80 percent more active, respectively, at desulfurizing petroleum fuel than conventional catalysts used in the mid-90s. These improvements have come about through better dispersion of the active metal on the catalyst substrate.

Another catalyst vendor shared some information about its catalyst development program which involves advances in the geometry of its substrate. These advances have resulted in significant improvements in the contact of diesel fuel with the catalyst. The vendor also shared that it is combining its substrate technology with other reactor enhancements to further increase the contact between diesel fuel and the catalyst and hydrogen. Preliminary tests suggest that this combination could improve the catalyst activity by at least a minimum of two.

Thus, by itself, changing to a more active catalyst can reduce sulfur significantly. Based on the history of the industry, improvements in catalyst performance can be anticipated over time to result in roughly a 25 percent increase in catalyst activity every 4 years. Vendors have informed EPA that the cost of these advanced catalysts is very modest relative to less active catalysts. This will help to reduce the reactor size needed.

The second type of improvement which can be made to improve 500 ppm hydrotreating is to reduce the concentration of hydrogen sulfide, which reduces the inhibition of the desulfurization and hydrogenation reactions. Hydrogen sulfide can be removed by chemical scrubbing. Haldor-Topsoe indicates that decreasing the concentration of hydrogen sulfide at the inlet to a co-current reactor by three to six volume percent can decrease the average temperature needed to achieve a specific sulfur reduction by 15-20^{o}C, or reduce final sulfur levels by more than two-thirds. UOP projects that scrubbing hydrogen sulfide from recycle hydrogen can reduce sulfur levels from roughly 285 to 180 ppm in an existing hydrotreater.

The third type of improvement which can be made to current distillate hydrotreating is to improve vapor-liquid contact. Akzo Nobel estimates that an improved vapor-liquid distributor can reduce the temperature necessary to meet a 50 ppm sulfur level by 10 ^oC, which in turn would increase catalyst life and allow an increase in cycle length from 10 to 18 months. Based on the above data from Haldor-Topsoe, if temperature were maintained, the final sulfur level could be reduced by 50 percent. Similarly, in testing of an improved vapor-liquid distributor in commercial use, Haldor-Topsoe found that the new distributor allowed a 30 percent higher sulfur feed to be processed at 25^{o}C lower temperatures, while reducing the sulfur content of the product from 500 to 350 ppm. Maintaining temperature should have allowed an additional reduction in sulfur of more than two-thirds. Thus, ensuring adequate vapor-liquid contact can have a major impact on final sulfur levels.

The fourth type of improvement possible is to increase hydrogen partial pressure and/or purity. As discussed above, this increases the rate of both desulfurization and hydrogenation reactions. Haldor-Topsoe indicates that increasing hydrogen purity is preferable to a simple increase in the pressure of the hydrogen feed gas, since the latter will also increase the partial pressure of hydrogen sulfide later in the process, which inhibits both beneficial reactions. Haldor-Topsoe projects that an increase in hydrogen purity of 30 percent would lower the temperature needed to achieve the same sulfur removal rate by eight to nine ^{o}C. Or temperature could be maintained while increasing the amount of sulfur removed by roughly 40 percent. Hydrogen purity can be increased through the use of a membrane separation system or a PSA unit. UOP project that purifying hydrogen can reduce distillate sulfur from 180 to 140 ppm from an existing hydrotreater.

The fifth type of improvement is to increase reactor temperature. Haldor-Topsoe has shown that an increase of 14^{o}C while processing a mix of SRLGO and LCO with its advanced TK-574 CoMo catalyst will reduce sulfur from 120 ppm to 40 ppm.[20] UOP projects that a 20 ^{o}F increase in reactor temperature would decrease sulfur from 140 to 120 ppm. The downside of increased temperature is reduced catalyst life (i.e., the need to change catalyst more frequently). This increases the cost of catalyst, as well as affects highway diesel fuel production while the unit is down for the catalyst change. Still, current catalyst life currently ranges from six to 60 months, so some refiners could increase temperature and still remain well within the range of current industry performance. The relationship between temperature and life of a catalyst is a primary criterion affecting its marketability. Thus, catalyst suppliers generally do not publish these figures.

Sixth, additional sulfur can be removed by increasing the amount of recycle gas sent to the inlet of the reactor. However, the effect is relatively small. Haldor-Topsoe indicates that a 50 percent increase in the ratio of total gas/liquid ratio only decreases the necessary reactor temperature by six to eight ^{o}C. Or, temperature can be maintained and the final sulfur level reduced by 35-45 percent.

Seventh, reactor volume can be increased. UOP projects that doubling reactor volume would reduce sulfur from 120 to 30 ppm.

These individual improvements described cannot be simply combined, either additively or multiplicatively. As mentioned earlier, each existing distillate hydrotreater is unique in its combination of design, catalyst, feedstock, and operating conditions. While the improvements described above are probably indicative of improvements which can be made in many cases, it is not likely that all of the improvements mentioned are applicable to any one unit; the degree of improvement could either be greater than, or less than the benefits that are indicated.

Therefore, many refiners may have to implement one additional technical change listed by UOP to be able to meet the 15 ppm cap standard. This last technical change is to add a second stage to current single stage 500 ppm hydrotreaters. This second stage would consist of a second reactor, and a high pressure, hydrogen sulfide scrubber between the first and second reactor. The compressor would also be upgraded to allow a higher pressure to be used in the new second reactor. Assuming use of the most active catalysts available in both reactors, UOP projects that converting from a one-stage to a two-stage hydrotreater could produce 5 ppm sulfur relative to a current level of 500 ppm today.

In addition to these major technological options, refiners may have to debottleneck or add other more minor units to support the new desulfurization unit. These units could include hydrogen plants, sulfur recovery plants, amine plants and sour water scrubbing facilities. All of these units are already operating in refineries but may have to be expanded or enlarged.

Overall, Akzo-Nobel projects that current hydrotreaters can be modified short of a revamp to achieve 50 ppm sulfur. Acreon/IFP/Procatalyse is less optimistic, believing that more than a catalyst change will be necessary to meet this sulfur level.[21] BP-Amoco projects that a 70 percent improvement in catalyst activity could reduce sulfur from a current hydrotreater meeting a 500 ppm sulfur specification to 30 ppm.[22] While this improvement is somewhat greater than the 50 percent improvement measured by Akzo Nobel at current desulfurization severity, it indicates that it may be possible to improve current hydrotreaters to produce distillate sulfur levels in the 50-100 ppm range. Thus, it appears that additional reductions needed to meet a 15 ppm cap would require additional measures. To assess the degree that these measures would be needed, it is useful to examine the commercial and pilot plant performance of distillate hydrotreaters to achieve very low sulfur levels.

5.2.2.3 Low Sulfur Performance of Distillate Hydrotreating

Data from both pilot plant studies and commercial performance are available which indicate the capability of various hydrotreating technologies to reduce distillate sulfur levels to very low levels. While many reports of existing commercial operations are available which focus on reducing sulfur to meet a 500 ppm sulfur standard or somewhat below that sulfur level, studies of achieving lower sulfur levels (e.g., 10-50 ppm) are associated with also reducing aromatics content significantly. This combination is related to the fact that Swedish Class II diesel fuel must meet a tight aromatics specification in 2005 along with a 10 ppm sulfur cap standard. Other European diesel fuel must also meet a 10 ppm sulfur cap standard.

Another study projected the technology and resulting cost to reduce sulfur for EPA, the Engine Manufacturers Association retained Mathpro for this study. The projections of this study will be discussed in the next chapter on the economic impacts of this rule. The discussion in this chapter will focus on the available pilot plant and commercial data demonstrating the achievement of low sulfur levels. It is worth noting that until the 15 ppm cap standard was established for highway diesel fuel in the U.S. and the announcements by the German government to seek sulfur levels as low as 10 ppm, there had been little effort by industry to develop technology capable of such a level across the diesel pool. Recent advancements by catalyst manufacturers demonstrating the feasibility of producing diesel fuel which meets these levels through pilot plant testing and some commercial demonstrations should be considered a first-generation of technology, with new and continual advancements expected over time.

Starting with SynTechnology, as of August 2, 1999, there were 24 units either in operation or in the process of being constructed. The purpose for each of those units ranged from desulfurization to desulfurization plus dearomatization to mild hydrocracking. Of particular interest here is a revamp of an existing two reactor distillate hydrotreater at the Lyondell-Citgo refinery in Texas. The revamped unit was designed to process a low-cost feed very heavily weighted towards cracked material (65-70 percent LCO and LCGO). One existing reactor was converted to SynSat Technology, while the other was used simply as a flash drum. A new first-stage reactor was added. Both reactors were designed to operate in a co-current fashion. Pilot plant studies predicted average sulfur and aromatics levels of seven ppm and 31 volume percent, respectively, based on feed sulfur and aromatics levels of 11,900 ppm and 53 volume percent, respectively. The unit exceeded expectations in the case of sulfur, producing an average sulfur level of less than five ppm from a feed sulfur level of 13,800 ppm. The actual aromatic level achieved was above the target by four volume percent, but the feed aromatic level was five volume percent higher than expected. Thus, the net reduction in aromatic content in terms of volume percent was still higher than found in the pilot plant. ABB Lummus and Criterion indicate that their catalyst technology is sufficiently flexible to focus on the deep desulfurization with or without the significant aromatics reduction seen here. This is reflected in their projection of the technology needed to meet a 15 ppm sulfur cap which is discussed in the next chapter.

While this two-stage unit initially produced less than 5 ppm product, it does not do so consistently. The primary purpose of the unit is to increase cetane so that the product can be blended directly into diesel fuel. The primary sulfur reduction requirement is to protect the noble metal catalyst in the second stage reactor. This generally requires that the product from the first stage be less than 50 ppm. Thus, if the cetane specification is being met at less severe sulfur reduction conditions, there is no incentive to reduce sulfur any further than necessary for catalyst protection. In addition, the unit is seeing a heavier feedstock than designed, and the desulfurization reactor is being operated at a lower temperature than designed to increase the cycle lengths.

IFP, in conjunction with various catalyst manufacturers, offers its Prime D technology for deep desulfurization, aromatics saturation and cetane improvement.[23] Using a NiMo catalyst, IFP's Prime D process can produce distillate sulfur levels of 10 ppm from SRLGO and of less than 20 ppm from distillate containing 20-100 percent cracked material using a single stage reactor. With a two-stage process, less than one ppm sulfur can be achieved.

United Catalysts and Sud-Chemie AG have published data on the performance of their ASAT catalyst, which uses platinum and palladium.[24] The focus of their study was to reduce aromatics to less than 10 volume percent starting with a feed distillate containing up to 500 ppm sulfur and at least 100 ppm nitrogen. Starting with a feed distillate containing 400 ppm sulfur and 127 ppm nitrogen and 42.5 volume percent aromatics, the ASAT catalyst was able to reduce sulfur to eight to nine ppm, essentially eliminate nitrogen and reduce aromatics to two to five volume percent. Hydrogen consumption was 800-971 standard cubic feet per barrel (SCFB).

Akzo Nobel recently presented a summary of the commercial experience of about a years worth of operations of their STARS catalyst for desulfurizing diesel fuel at the BP-Amoco refinery in Grangemouth, UK.[25] The original unit was designed to produce 35,000 barrels per day of diesel fuel at 500 ppm treating mostly straight run material, but some LCO was treated as well. Akzo Nobel’s newest and best catalyst (KF 757 at that time) was dense-loaded[D] into the reactor to produce 45,000 barrels per day diesel fuel at 10 - 20 ppm (to meet the 50 ppm cap standard). From the data, it was clear to see that as the space velocity changed, the sulfur level changed inversely proportional to the change in space velocity. Usually when the space velocity dipped below 1.0, the sulfur level dropped below 10 ppm. At that refinery, however, it was not necessary to maintain the sulfur level below 10 ppm.

These studies indicate the commercial feasibility of producing diesel fuel with 10 ppm or less sulfur. The primary issue remaining is to commercially demonstrate that the 15 ppm cap standard can be met using the desulfurization/hydrogenation method without saturating much of the aromatics in diesel fuel, especially with a feedstock blend which contains a substantial amount of cracked material. The ease or difficulty of accomplishing this depends on the amount of cracked stocks that the refiner blends into diesel fuel. A few refiners have the possibility of shifting some of the sterically hindered compounds to fuels complying with less stringent sulfur standards, such as off-highway diesel fuel and heating oil. However, our desulfurization technology feasibility analysis did not considered the occurrence of feedstock shifting as necessary for refiners to meet the proposed diesel sulfur standards.

5.2.3 Phillips S-Zorb Sulfur Adsorption

A prospective diesel desulfurization process was announced by Phillips Petroleum in late 2001.[26] This process is an extension of their S-Zorb process for gasoline and thus is called S-Zorb for diesel fuel. The process is very different from conventional diesel fuel hydrotreating in that instead of reacting the sulfur with hydrogen over a catalyst to form H2S, the S-Zorb process adsorbs the sulfur molecule onto a sorbent for later removal. At a pressure of 275 - 500 pounds per square inch gauge (psig) and at a temperature of 700 - 800 Fahrenheit and in the presence of

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[D] Dense loading is a process of packing a certain volume of catalyst into a smaller space than conventional catalyst loading.

hydrogen in the S-Zorb reactor, the sulfur atom of the sulfur-containing compounds adsorbs onto the sorbant. The catalyst activity of the sorbent next cleaves the sulfur atom from the sulfur-containing hydrocarbon. To prevent the accumulation of sulfur on the catalyst, the catalyst is continually removed from the reactor. From the reactor, the sorbent is moved over to a receiving vessel by an inert lift gas, which likely is nitrogen, and then in the receiving vessel the lift gas and the entrained diesel fuel is removed from the sorbent. The sorbent next drops down into a lockhopper which facilitates the movement of the sorbent to the regenerator. In the regeneration vessel, the sulfur is burned off of the sorbent with oxygen and the generated SO2 is sent to the sulfur plant. The regenerated sorbent then drops down into a reducer vessel where the sorbent is returned back to its active state. The sorbent is then recycled back to the reactor for removing more sulfur. Because the catalyst is continuously being regenerated, Phillips estimates that the unit will be able to operate 4 - 5 years between shutdowns. Because untreated distillate can contain several percent sulfur, Phillips believes that its S-Zorb process for diesel could get overwhelmed by the amount of sulfur which is adsorbing onto the catalyst. However, some refiners who run sweet crudes and produced low sulfur non-highway diesel volumes (from straight run diesel and hydrocrackate diesel) may have lower uncontrolled nonroad sulfur levels. These refiners may be able to use the S-Zorb process to lower their nonroad diesel sulfur. Thus, the S-Zorb process may not be able to economically treat all untreated distillate streams which are high in sulfur, and would be best suited to treat distillate containing 500 ppm sulfur or less.

Phillips has been involved in sorbent technology at least as far back as 1980 which is when the company filed a patent application for sorbent technology. However, it seems apparent that Phillips did not develop its S-Zorb technology until much later as it filed for a patent for a technology for circulating sorbent during March of 1997. The purpose of the March, 1997 patent was to remove hydrogen sulfide. The technical focus of that patent was both the sorbent chemistry and the sorbent handling technology. The catalyst content was specified to be alumina, silica, zinc oxide and metal oxide (probably in the form of nickel oxide) and the sorbent size was specified to be in the range of 20 to 500 micrometers. Then in August of 1999, Phillips filed a patent for using its sorbent recirculating technology to desulfurize cracked gasoline and diesel fuels. The sorbent change as specified in the patent was to add substantially reduced valence nickel to enable the removal of sulfur from the targeted refinery streams. Then Phillips filed a patent in May of 2001 for an improved catalyst to desulfurize cracked gasoline and diesel fuel. The change was to add a calcium compound which increases the porosity of the sorbent and increases the resistance to deactivation. The latest patent also listed the potential candidates for metal promotors to include cobalt, nickel, iron, manganese, copper, molybdenum, silver, tungsten tin and vanadium, or mixtures of these metal oxides, with valences of 2 or less.

Phillips' S-Zorb diesel desulfurization process has been demonstrated in a pilot plant which started up in early 2002. This pilot plant has provided Phillips data on how the unit would operate processing varying formulations of diesel fuel or diesel fuel blendstocks. The pilot plant testing data which has been released by Phillips has shown that diesel fuels blended with LCO can be desulfurized down below 5 ppm. Phillips has also shown that straight run diesel fuel can be desulfurized below measurable levels and a 100 percent LCO stream can be desulfurized down to 10 ppm. These testing results are summarized in chapter 7 where we use the data to develop the inputs for our refinery cost model. Phillips is constructing a commercial unit to demonstrate their S-Zorb diesel desulfurization unit. Phillips is completing the engineering phase of this project to design this unit and is expected to begin the construction for an estimated start-up date during early 2004.

While the S-Zorb diesel desulfurization process has not been demonstrated commercially, Phillips has demonstrated the S-Zorb technology for desulfurizing gasoline. An S-Zorb gasoline desulfurization unit started up at Phillips' Borger refinery in April of 2001. According to Phillips, their gasoline desulfurization unit has operated as designed for the past two years. The successful demonstration of their gasoline desulfurization unit at Borger has interested many refiners in using S-Zorb gasoline desulfurization process for complying with the upcoming Tier 2 gasoline sulfur program. Starting in 2004 many refiners will need to be starting up their gasoline desulfurization units for complying with the 30 ppm Tier 2 gasoline sulfur standard which phases in from 2004 to 2006. Phillips shared with us in late 2002 that they have licensed their S-Zorb for gasoline processing for installation in 9 refineries. That the Borger S-Zorb gasoline desulfurization unit has operated as designed and that there are 9 new S-Zorb gasoline units planned to start up demonstrates that there is agreement within the refining industry that the S-Zorb process works.

Much of the refining industry's trust with the S-Zorb gasoline desulfurization unit is likely to apply to S-Zorb for diesel fuel as well. First, the sorbent has been shown to be effective at adsorbing sulfur, releasing the sulfur when it is burned and then at being regenerated for reuse. Also, the S-Zorb unit has been shown to be able to move the sorbent out of the reactor into a number of different vessels for handling and treatment and then recycling back to the reactor. The part of diesel fuel desulfurization which cannot be demonstrated with the S-Zorb gasoline desulfurization unit is how effectively the sorbent would be able to adsorb and cleave the sulfur molecule from the sulfur-containing molecules of diesel fuel. However, that part of the S-Zorb diesel fuel desulfurization unit should be able to be demonstrated with testing in the pilot plant. Phillips can even test the diesel fuels from specific refineries in their pilot plant to help design the S-Zorb unit for those refineries. Thus, Phillips is marketing its diesel fuel desulfurization unit even before their diesel fuel desulfurization commercial demonstration unit has started up.

Most refiners, however, are very conservative and would not be willing to only rely on pilot plant testing for a unit which would likely cost tens of millions of dollars, and without its proper operation they might not be able to operate. Thus, they would want to see a particular technology operating as a commercial unit for a significant period of time, such as two years, before trusting that the technology is reliable.

Since the process has never been demonstrated commercially on diesel fuel, the commercial demonstration unit will go a long way toward proving to refiners that the Phillips process works as designed. In particular, the sulfur compounds in diesel fuel are different, usually more refractory, than those in gasoline. Phillips reports, though, that the absorption catalyst more readily desulfurizes the sterically hindered sulfur compounds than the thiophenes (single ring compounds which contain sulfur) which must be desulfurized in gasoline. This suggests the possibility that S-Zorb for diesel may actually desulfurize diesel fuel more easily than gasoline. Phillips projects that they will have an S-Zorb diesel desulfurization commercial unit up and running during the first quarter of 2004. After hearing Phillips' timeline for developing the S-Zorb diesel desulfurization process, and understanding the scrutiny by refiners for new desulfurization processes, it seems that refiners may consider this process too risky for complying with the 500 ppm cap in 2007, especially since the demonstration unit will be a revamp of an existing hydrotreating unit for producing 15 ppm diesel fuel. However, after seeing the commercial unit producing 15 ppm sulfur for the Highway Program for several years, we believe that this process will be a serious contender for 2010 for nonroad.

5.2.4 Linde Isotherming

A professor at the University of Arkansas has applied some ingenuity in reaction chemistry to diesel desulfurization. After conceiving of this process, he started a company named Process Dynamics and then took the new technology to Linde for development and eventual licensing. The reaction technology reacts diesel fuel with hydrogen, which is totally dissolved in the diesel fuel, in a plug flow reactor. Since the hydrogen gas is dissolved into the diesel fuel, the reactor only needs to be designed to handle a liquid, instead of the two phase reactors designed for conventional hydrotreating. Since only about 75 standard cubic feet of hydrogen can be dissolved into each barrel of diesel fuel and the hydrogen consumption for a particular desulfurization step can be much higher than that, this technology cannot be a once-through process. Process Dynamics solved that limitation by recycling the feed after a very short residence time in the reactor to recharge the liquid with more hydrogen and to mix this recycle with some untreated diesel fuel before sending it to the reactor. Thus, the recycled partially desulfurized diesel fuel acts like a diluent to the fresh feed controlling the hydrogen consumption, and the diesel fuel is recharged with hydrogen and sent to the reactor to be desulfurized several times as it is being treated.

The Linde Isotherming process has a couple apparent advantages over conventional desulfurization. First, since the hydrogen is already in the liquid phase, the hydrotreating reaction can occur much more quickly because, as described by Linde, the kinetics of conventional hydrotreating are mass transfer limited which is the rate at which gaseous hydrogen can transfer into the liquid phase. Linde makes this point by the following reaction equations. For conventional hydrotreating the following two equations apply:

$rg = kg\ (PH2 - P \times H2)$ (rate of hydrogen mass transfer into the liquid phase)

Where:
rg = transfer rate of hydrogen gas into diesel fuel.
kg = hydrogen gas mass transfer rate.
PH2 = Partial pressure of hydrogen in the gas phase.
P×H2 = Partial pressure of hydrogen at the catalyst.

and

rs = ks T[S][P×H2] (rate of desulfurization at the catalyst site)

Where:
rs = rate of reaction of sulfur.
ks = reaction rate constant for sulfur removal.
P×H2 = partial pressure of hydrogen at the catalyst.
T = temperature in degrees absolute.
[S] = concentration of sulfur.

If the desulfurization rate of reaction (rs) is much slower than the rate at which hydrogen can dissolve into diesel fuel (rg), then there would probably not be any benefit for the Linde Isotherming process. However, according to Linde, the rate of reaction for desulfurization is faster than the rate of mass transfer, thus, the rate of reaction for diesel hydrotreating is limited by the mass transfer of hydrogen into diesel fuel. Thus, the Linde process increases the rate of reaction by dissolving the hydrogen needed for the reaction into the liquid phase prior to sending this liquid to the reactor. The faster rate of reaction is indicated by the fact that the Linde desulfurization process which can desulfurize a unhydrotreated distillate comprised of a typical mix of distillate blendstocks down to about 500 ppm at a space velocity of 8 hour^{-1}. Conversely, conventional hydrotreating requires a space velocity of about 2 hour^{-1} to accomplish the same task.

There are a two important benefits to the Linde process because it has a higher space velocity. One benefit is that the amount of catalyst needed for the Linde process is lower. By definition, if the same volume of feed can be treated faster than another process, the amount of catalyst needed is proportionally lower by the inverse proportion of the space velocity. The second advantage of having a faster space velocity is that the reactors are sized much smaller to hold the lower volume of catalyst. Both of these benefits result in lower costs for the Linde Isotherming deslfurization process. The lower catalyst volume required by Linde Isotherming costs proportionally less because the Linde desulfurization process uses the same catalysts as conventional hydrotreating. Similarly, the smaller reactor volume reduces the capital costs, although in this case the cost reduction is not necessarily proportionally less as smaller reactors have a poorer economy of scale compared to larger reactors.

The Linde engineers point out that the Isotherming process also has other benefits over conventional hydrotreating. When some of the aromatics in diesel fuel are saturated during the desulfurization process, heat is generated. In the case of conventional hydrotreating, much of this heat is intentionally quenched away in an attempt to avoid excessive temperature excursions. Excessive temperature excursions and local low hydrogen concentration can lead to coking which is a constant problem with conventional hydrotreating. However, the higher space velocity of the Linde process coupled with the fact that the feed is diluted by the recycle stream allows for better control of the process temperature. Furthermore, the ready availability of hydrogen in the liquid phase along with the better temperature control prevents most of the coking from occurring. Thus the internally generated heat can be conserved, instead of being quenched away, and used to heat the process. The conserved heat means that no external heating is required which provides a savings in natural gas consumption relative to conventional hydrotreating. However, a small heater is still needed to heat the feed during start-up.

Another advantage of the Linde desulfurization process is that it does not need a hydrogen gas recycle compressor. Because the hydrogen pumped into solution and going to the reactor is either used up or it remains in solution, there is no residual hydrogen gas to recycle. Compressors operating at the pressures that diesel fuel desulfurization occurs are expensive, long time delivery items. Thus, by omitting the recycle gas compressor and using smaller reactors, the Linde desulfurization process saves substantial capital costs compared to conventional hydrotreating which likely means a somewhat shorter construction time. The smaller reactors and heater coupled with the fact that a recycle gas compressor is not needed means that the Linde process requires a smaller footprint compared to conventional hydrotreating

While aspects of the Linde Isotherming desulfurization process for diesel fuel desulfurization are novel compared to conventional diesel desulfurization, many aspects of the process are the same. Much of the list of required equipment is the same for the Linde process as for conventional hydrotreating. Table 5.2-1 shows both the similarities and differences between the two.

Table 5.2-1
Major Equipment Needed for Linde Isotherming and Conventional Hydrotreating

	Linde Isotherming	Conventional Hydrotreating
Heat Exchangers	Yes	Yes
Heater	Yes (small and for startup only)	Yes
Hydrogen gas compressor	Yes	Yes (for hydrogen makeup)
Mixers for dissolving hydrogen into the diesel fuel	Yes	No
Reactor (s)	Yes (2 - 4 small plug flow)	Yes (1 - 2 large trickle bed)
Reactor distributor	No	Yes
High pressure flash drum and hydrogen separator	Yes	Yes
Low pressure separator	Yes	Yes
Recycle hydrogen compressor	No	Yes
Recycle hydrogen gas scrubber	No	Yes

Linde has accumulated some data on the Isotherming desulfurization process from testing which they have done with their pilot plant. Linde started up a pilot plant in late 2001. Recently, Linde installed a commercial demonstration unit of their technology at a Giant refinery as a revamp to an existing highway hydrotreater to demonstrate compliance with the highway diesel fuel 15 ppm sulfur cap standard which begins in mid 2006. The unit was started up in September of 2002 and the Linde engineers have been working with the refinery engineers to optimize the unit for the refinery.

5.2.5 Chemical Oxidation and Extraction

Another desulfurization technology based on chemical oxidation is being pursued by Unipure and Petrostar.[27] For theses companies, the chemical oxidation desulfurization of diesel fuel is accomplished by first forming a water emulsion with the diesel fuel. In the emulsion, the sulfur atom is oxidized to a sulfone using catalyzed peroxyacetic acid. With an oxygen atom attached to the sulfur atom, the sulfur-containing hydrocarbon molecules becomes polar and hydrophilic and then move into the aqueous phase. These sulfone compounds can either be desulfurized or be converted to a surfactant which could be sold to the soap industry at an economically desirable price. The earnings made from the sales of the surfactant could offset much of the cost of oxidative desulfurization.

Petrostar has a bench scale pilot plant up and running and they intend to demonstrate their technology next with a commercial demonstration unit. Unipure is in the process of setting up a pilot plant and it is expected to be up and running by mid 2003.

Early in 2003, Lyondell announced that they had recently developed a chemical oxidation desulfurization technology. This process is similar in some ways to Unipure's and Petrostar's oxidation processes, but also different in some pronounced ways. The process is similar in that the process uses oxidation compounds to oxidize the sulfur compounds to sulfones and then removes relies on extraction to remove the sulfones. The differences are that instead of the using expensive peroxyacetic acid to create sulfones, this process uses t-butyl hydroperoxide oxidant to convert sulfur species in diesel to sulfones (this eliminates the need to recycle a co-oxidant acid). The oxidant is degraded t-butyl alcohol during the conversion of sulfur species to sulfones. The T-butyl alcohol by product can be converted to MTBE or isooctane or used as fuel in the refinery. T- butyl hydroperoxide is not as corrosive as peroxyacetic acid, thus Lyondell’s process is projected to be constructed from less expensive metallurgy. Lyondell has demonstrated pilot plant success desulfurizing 500 ppm diesel fuel to below 10 ppm and plans to have a commercial plant operable by late 2003 to early 2004. Lyondell’s technology was announced too late be incorporated into this analysis but we intend to stay abreast as they develop this new technology .

5.2.6 FCC Feed Hydrotreating

At the beginning of this section, it was mentioned that sulfur could be removed from distillate material early or late in the refining process. Early in the process, the most practical place to remove sulfur is prior to the FCC unit. The FCC unit primarily produces gasoline, but it also produces a significant quantity of LCO.

Many refineries already have an FCC feed hydrotreating unit. The LCO from these refineries should contain a much lower concentration of sterically hindered compounds than refineries not hydrotreating their FCC feed. Adding an FCC feed hydrotreating is much more costly than distillate hydrotreating. Just on the basis of sulfur removal, FCC feed hydrotreating is more costly than distillate hydrotreating, even considering the need to reduce gasoline sulfur concentrations, as well. This is partly due to the fact that FCC feed hydrotreating by itself is generally not capable of reducing the level of diesel fuel sulfur to those being considered in this rule. However, FCC feed hydrotreating provides other environmental and economic benefits. FCC feed hydrotreating decreases the sulfur content of gasoline significantly, as well as reducing sulfur oxide emissions from the FCC unit. It also increases the yield of relatively high value gasoline and LPG from the FCC unit and reduces the formation of coke on the FCC catalyst. For individual refiners, these additional benefits may offset enough of the cost of FCC hydrotreating to make it more economical than distillate hydrotreating. However, these benefits are difficult to estimate in a nationwide study such as this. Also, feed hydrotreating is not expected to, by itself, enable a refinery to meet either the 500 or the 15 ppm cap standards. Thus, this study will rely on distillate hydrotreating as the primary means with which refiners would meet the 15 ppm sulfur cap. For those refiners who would choose FCC feed hydrotreating, their costs would be presumably lower than distillate hydrotreating and the costs estimated in the next chapter can then be considered to be somewhat conservative in this respect.

5.3 Feasibility of Producing 500 ppm Sulfur Nonroad Diesel Fuel in 2007

5.3.1 Expected use of Desulfurization Technologies for 2007

To enable our determination of whether it is feasible for the refining industry to meet the proposed 2007 sulfur cap standard, and also to estimate the cost of complying with the proposed sulfur standard (see Chapter 7), we needed to project the mix of technologies that would be available and used for compliance. We considered several different factors for projecting the mix of technologies which would be used. First and foremost, we considered the time which refiners will have to choose a new technology which is important because of the relatively short timeline allowed for compliance. Second, we considered whether the technology would be available for 2007 and if the technology is available, how proven it is. Third, we considered whether the technology is cost-competitive by comparing it to other technologies. If a refiner finds that technology is lower cost than another, it is more likely to use that technology. We also considered whether the technology is available from an industry-trusted vendor which has proven itself to the industry by providing other successful refining technologies and particularly if the vendor has proven itself in the U.S. Finally, we considered the capability of the vendor to meet the demand of the industry. We considered all these issues for each technology, but as described below, some of these issues are more prominent than others.

To comply with the proposed 500 ppm sulfur standard in 2007, refiners will have to decide what technology they will want to use several years before the standard needs to be met. Several years are needed to perform a preliminary design, complete a detailed design, purchase the hardware needed, obtain the air quality permits needed, and then install and start up the hardware. Since this rulemaking is expected to be promulgated sometime in 2004, this would provide refiners three full years to comply with the 500 ppm sulfur standard if it is promulgated as predicted. Because refiners need about 3 years to complete the mentioned steps to have a working new unit, there is little time to shop around for a new desulfurization technology which is just beginning to prove itself. A thorough review of a newer technology can take months, thus if refiners do not have this extra time, they will tend toward the technologies with which they are familiar. See the next section for a more detailed discussion about the leadtime issues for the 2007 standard.

Of the various technologies which we list above for desulfurizing diesel fuel, conventional hydrotreating is by far the most familiar to refiners. Refiners are using conventional hydrotreating to meet the current highway diesel fuel 500 ppm sulfur cap standard. In the U.S. there are about 90 distillate hydrotreaters with virtually all of them being conventional hydrotreaters operating since 1993 or before. The one exception is a Linde Isotherming commercial demonstration unit which started up recently at a Giant refinery in New Mexico. Phillips S-Zorb, the two oxidation and extraction and biodesulfurization technologies are all being demonstrated by pilot plants only. Of those being demonstrated by a pilot plant, Phillips is expected to start a highway diesel fuel commercial demonstration unit in early 2004. However refiners usually want to see that a refinery unit has operated successfully for at least two years to ensure that it will operate with high reliability and low maintenance requirements.[E] In 2004, biodesulfurization, oxidation and extraction are not expected to have units operating at all. Phillips may have a diesel fuel desulfurization unit operating by then, but certainly it will not be operating for two years. While Phillips has a gasoline desulfurization operating now, refiners may be skeptical that it truly demonstrates the technology for diesel desulfurization. The Linde desulfurization unit which is installed now and has started to accrue valuable commercial experience will have accumulated somewhat less than two years of commercial experience by then.

After considering the above issues, it seems that the lack of an excess of leadtime is the central issue of whether refiners will choose between conventional hydrotreating and other advanced desulfurization technologies for 2007. Refiners would not have the luxury of many months needed to carefully consider the advanced technologies which are still in the development and demonstration stage, so we believe that this issue is the most critical affecting refiners choice of desulfurization technologies for 2007. For these reasons, we believe that refiners would default to what they know will work, which is conventional desulfurization. Since there are multiple vendors which can provide the preliminary engineering design and any followup support for conventional hydrotreating, these vendors would not be overly taxed and would be able to serve the refiners which will need to put in desulfurization units for 2007.

5.3.2 Leadtime Evaluation

Refiners must have sufficient leadtime to design, construct and start up desulfurization technology to meet the 500 ppm standard if this standard is to be implemented smoothly and

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[E] Refiners want low maintenance refining units because they have cut back their engineering staff to reduce their refining costs to improve their margins and thus will seek units which are consistent with that strategy.

without undue economic impacts. If one or more refiners were unable to comply on time, it would have major repercussions for the refiner and potentially for the national fuel supply. If some refiners who were planning on producing 500 ppm NRLM fuel could not do so on time and could not buy credits, they would have to sell their high sulfur distillate as heating oil, export this distillate or temporarily cease production. As discussed below in Section 5.8, heating oil would no longer be widely distributed in many markets. Thus, selling large quantities of heating oil may require distressed pricing and the absorption of trucking costs. Exportation would be very costly for refiners not located on an ocean coastline. Temporary closure obviously would result in serious financial loss. In addition, users of NRLM diesel fuel would likely face high fuel prices. Fuel prices respond quickly to supply shortages. Significant price increases would be expected if refiners were not able to fulfill demand for NRLM diesel fuel starting in June 1, 2007. Thus, providing adequate leadtime for refiners to design, construct and prove out the necessary new hydrotreaters is critical to avoiding serious economic harm to both the refining and NRLM industries.

We project that refiners would use conventional hydrotreating to meet the 500 ppm standard beginning on June 1, 2007. Of the 42 refineries projected to produce 500 ppm NRLM diesel fuel beginning in 2007, 13 are projected to do so with either no or minor modifications to their highway diesel fuel hydrotreaters. These refineries produce a relatively small volume of non-highway diesel fuel compared to their highway production. The remaining 29 refineries would need to design and construct a new hydrotreater to produce 500 ppm NRLM fuel.[F] This is roughly 20% of all U.S. refineries producing transportation fuels today. Thus, the time available between the date of the final rule and June 1, 2007 must be sufficient across a wide spectrum of refiners and situations.

EPA has conducted two leadtime assessments for the refining industry in the past 4 years. One was conducted for the Tier 2 gasoline sulfur program.[G] The other was conducted as part of our review of progress being made towards compliance with the 15 ppm sulfur, highway diesel fuel program.[H] The results of both of these assessments are reviewed below and then applied to the proposed NRLM sulfur control program.

5.3.2.1 Tier 2 Gasoline Sulfur Program

Chapter IV of the Final RIA for the Tier 2 gasoline sulfur program presented the following table which contains the results of its leadtime assessment

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[F] Without the proposed small refiner provisions, an additional 20 refineries would have to produce 500 ppm NRLM fuel by June 1, 2007, including 19 refineries owned by small refiners.

[G] Final Regulatory Impact Analysis, Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, U.S. EPA, December 1999.

[H] “Highway Diesel Progress Review,” U.S., EPA, June 2002, EPA420-R-02-016.

Table 5.3-1
Leadtime Projections Under the Tier 2 Gasoline Sulfur Program (years)

Project Stage	Naphtha/Gasoline Hydrotreating		More Major Refinery Modification (e.g., FCC Feed Hydrotreating)	
	Time for Individual Step	Cumulative Time[a]	Time for Individual Step	Cumulative Time[a]
Scoping Studies	0.5-1.0[b]	0.5	0.5-1.0[b]	0.5
Process Design	0.5	1.0	0.5-0.75	1.0-1.25
Permitting	0.25-1.0	1.25-2.0	0.25-1.0	1.25-2.0
Detailed Engineering	0.5-0.75	1.5-2.25	0.5-1.0	1.5-2.25
Field Construction	0.75-1.0	2.0-3.0	1.0-1.5	2.5-3.5
Start-up/Shakedown	0.25	2.25-3.25	0.25	2.75-3.75

[a] Several of the steps shown can overlap.
[b] Projected to begin before Tier 2 gasoline final rule.

This table contains leadtime projections for two distinctly different approaches to gasoline sulfur control. The first, naphtha hydtrotreating, is more closely related to conventional distillate hydrotreating. In fact, a number of naphtha hydrotreating processes utilize fixed bed hydrotreating which is directly comparable to distillate hydrotreating. The second, FCC feed hydrotreating is more complex, extensive and costly. As discussed earlier in this chapter, some refiners might use FCC feed hydrotreating to facilitate the production of 500 ppm diesel fuel. However, this decision would likely have been tied to their compliance plans for the Tier 2 gasoline sulfur program, since FCC feed hydrotreating significantly reduces the sulfur content of gasoline, as well as diesel fuel. The Tier 2 gasoline sulfur standards are fully phased in for most refiners by 2006. Thus, it is highly unlikely that a refiner would just begin considering FCC feed hydrotreating as the result of this NRLM rule. We will therefore only focus on the portion of the table which addresses the leadtime for naphtha hydrotreating.

It should also be noted that the cumulative times listed in the table above are not simply the sum of the times for each step. Some steps overlap, in particular process design and permitting, permitting and detailed engineering, and detailed engineering and construction. The relationship between the time necessary for each step in the design and construction of naphtha and distillate hydrotreaters will be examined in detail. However, it would be useful first to review EPA's leadtime projections related to the 15 ppm highway diesel fuel cap.

5.3.2.2 15 ppm Highway Diesel Fuel Sulfur Cap

The rulemaking implementing the 15 ppm sulfur cap for highway diesel fuel did not evaluate the leadtime required for each individual step of the process. That rule provided 5.5 years of leadtime between promulgation and initial implementation. This amount of leadtime significantly exceeded that considered necessary to design and construct desulfurization equipment. This amount of leadtime was provided, since the timing of the 15 ppm sulfur cap was set primarily by the availability of highly efficient aftertreatment technology for diesel engines and not on refiners' ability to meet the 15 ppm standard.

EPA reviewed the progress that refiners were making towards complying with the 15 ppm highway diesel fuel cap in 2002. Part of this review included an assessment of the tasks which refiners had already completed and the length of time needed for those still remaining. The tasks considered were essentially the same as those listed in Table 5.3-1 above, with one exception. That was the inclusion of the need to develop a corporate strategy towards compliance in the initial step. This strategy involved a decision regarding the degree that the refiner was going to continue marketing highway diesel fuel and if so, whether he would comply with the 15 ppm standard initially in 2006 or later in 2010. However, diesel fuel can be sold to the highway or non-highway markets, involving compliance with very different sulfur standards. The flexibility afforded by the rule's temporary compliance option also gave refiners a choice of when they chose to comply with the 15 ppm cap. This issue didn't arise in the Tier 2 gasoline rule, since essentially all gasoline sold in the U.S. meets highway quality standards, and refiners have no other market for their gasoline feedstocks.

The results of the leadtime review are presented in the table below.

Table 5.3-2
Leadtime Assessment: Progress Review of 15 ppm Highway Diesel Fuel Cap

Project Stage	Time Allotted	Latest Start Date
Strategic Planning	0.25-2 years	----------
Planning and Front End Engineering[a]	0.5	Mid-2003
Detailed Engineering and Permits	1.0	Late 2003 - Early 2004
Procurement and Construction	1.25-2.5	October 2004
Commissioning and Start-Up	0.25-0.5	March 2006

[a] Labeled Process Design in Table 5.3-1.

By grouping several of the process steps shown in Table 5.3-1 this later assessment reduces the overlap between the various steps considerably. The primary overlap still remaining is between detailed engineering and permits and procurement and construction. While construction cannot begin until permits have been obtained, procurement can proceed. This is often essential to any time constrained refining project, due to the long leadtimes needed to fabricate specialized equipment.

Because the progress review was conducted over a year after the rule was promulgated, EPA did not add up the times associated with each step to develop a range of cumulative time requirements. Instead, we focused on the dates by which refiners should have begun each step to determine if they had indeed begun those steps which should have been started by the date of the assessment.

5.3.2.3 Leadtime Projections for Production of 500 ppm NRLM Diesel Fuel

We utilized the information for gasoline and highway diesel analyses to project the leadtime necessary for a wide spectrum of refiners to start producing 500 ppm NRLM diesel fuel. Beginning with strategic planning, refiners currently producing high sulfur diesel fuel/heating oil would have to decide whether they are going to continue producing high sulfur heating oil or produce 500 ppm NRLM diesel fuel. This would not likely be a difficult choice for many refiners, as the heating oil market would be too small in their area to support their entire production of high sulfur fuel. For those with a real choice, this step would likely involve discussions between the refining and marketing divisions of the firm, as well as with any common carrier pipelines used by the refiner. While many refiners would prefer to be able to observe their competition’s choices and the relative production volumes and prices of 500 ppm NRLM diesel fuel and high sulfur heating oil before making a decision, this is not possible. Given this, it seems reasonable to allow a relatively short period of time, 3-6 months to arrive at a corporate decision to participate in the NRLM or heating oil markets.

Scoping and screening studies refer to the process whereby refiners investigate various approaches to sulfur control. These studies involve discussions with firms which supply desulfurization and other refining technology, as well as studies by the refiner to assess the economic impacts of various approaches to meeting the sulfur standard. In the case of distillate desulfurization, a refiner would likely send samples of their various distillate streams to the firms marketing desulfurization technology to determine how well each technology removed the sulfur from that particular type of distillate (e.g., sulfur removal efficiency, yield loss, hydrogen consumption, etc.).

Under the Tier 2 rule, we projected that 0.5-.1.0 years would be required to evaluate the various naphtha desulfurization technologies which were or soon to be available. This extensive period of time was deemed appropriate due to the wide range of technologies available. More importantly, however, was the fact that many of the new gasoline desulfurization technologies had not have been demonstrated in actual refinery applications by the time of the final rule. Refiners naturally desire as much demonstrated experience with any new technology as possible prior to investing significant amounts of capital in these technologies. We believed that at a minimum, refiners should have 6 months after the final rule to assess their situation with respect to the final sulfur control program and select their vendor and technology. Because the Tier 2 gasoline sulfur standards phased in over two years, some refiners had more time than others before their new desulfurization equipment had to be operational. Thus, we expected refiners to take as much time as they could afford to select the particular desulfurization technology which was optimum for their situation. Thus, there was really no upper limit to the amount of time for this step.

The scoping and screening task which refiners would face with respect to the 500 ppm NRLM sulfur cap is both different and similar to the situation refiners faced with the Tier 2 gasoline program. The NRLM program would differ, because refiners had to choose between a wide variety of gasoline desulfurization technologies to comply with the Tier 2 sulfur standards. In contrast, above, we project that conventional hydrotreating would likely be the dominant choice for desulfurizing diesel fuel to 500 ppm in 2007. The similarity would exist, because refiners would have to consider how they are going to comply with the 15 ppm nonroad diesel fuel cap in 2010 when they design their conventional hydrotreater for 2007. While conventional hydrotreating is well understood, there are numerous ways to "conventionally hydrotreat" distillate. Variations exist in operating pressure, hydrogen purity, physical catalyst loading, etc. To avoid scrapping their conventional hydrotreaters after just three years, we project that the refiners building new conventional hydrotreating units for 2007 would plan these units to be easily revamped in 2010 to produce 15 ppm nonroad diesel fuel. Therefore, the specific conventional hydrotreating design selected for 2007 would have to mesh with their plan for 2010. At minimum, this would involve the selection of the operating pressure of the conventional hydrotreater, provision of physical space for additional equipment and the capacity of hydrogen supply and treatment lines. The selection of operating pressure is likely the most time critical, because of the long lead times involved in procuring pressure vessels. Some time for vendors to assess the performance of their 15 ppm technologies via pilot plants testing on specific refiners' diesel fuel samples should be included.

Fortunately, this process has been underway for some time involving refiners' highway diesel fuels. By mid-2004, this process should be essentially complete. Vendors' should have ample capacity to test refiners' NRLM diesel fuel samples, as well as have developed efficient approaches to translate test results into specific process designs. Thus, six months should be more than sufficient for refiners to make the necessary, critical choices about their conventional hydrotreater design. In fact, the selection of operating pressure could be made during the process design step, effectively reducing the amount of time to scoping and screening to three months.

The strategic decision to produce 500 ppm NRLM diesel fuel not only involves marketing, but an economic assessment of the cost of producing this fuel, both absolutely and relative to the competition. The scoping and screening studies are also not expensive to conduct. Refiners do not risk much to conduct them while they are still developing their corporate strategy. Also, the scoping and screening studies can go on concurrent with the development of a corporate strategy towards the rule. This means that the 3-6 months for strategic planning and the 3-6 months for scoping and screening can go on concurrently.

The time required for process design of a conventional distillate hydrotreater should be no greater than that for a naphtha hydrotreater or the revamp of a diesel fuel hydrotreater (i.e., six months in both Tables 5.3-1 and 5.3-2). In fact, the design of the naphtha hydrotreater may be more complex due to the desire to avoid too great a loss in octane from olefin saturation. Octane is not an issue with distillate hydrotreating. In general, the design of a grassroots distillate hydrotreater would be more complex than that of a revamp. However, here the revamp is to produce 15 ppm diesel fuel, a much more challenging task than producing 500 ppm diesel fuel.

Thus, six months should be sufficient for the process design of a 500 ppm NRLM unit. The cumulative time for the strategy, scoping and process design steps should range from 0.75-1.0 year, as the choice of distillate hydrotreating is clear.

Regarding permitting, EPA has taken a number of steps to help state/local permitting agencies to efficiently process refiners' requests for permits related to environmental-related projects such as these. Our experience with permits related to naphtha desulfurization indicates that 3-9 months would be a more realistic range, as opposed to the 3-12 months which was projected in the Tier 2 Final RIA. There, we identified the 12 month period as being a worse case scenario. Experience has confirmed this and we are not aware of any specific situations where obtaining a permit has taken this long and held up the project completion.

The detailed design and construction of a distillate hydrotreater could require some additional time relative to that for a naphtha hydrotreater due to the higher operating pressures required for distillate hydrotreating. Fewer firms fabricate higher pressure reactors and compressors. At the same time, less time should be required than required for a FCC feed hydrotreater. FCC feed hydrotreating usually occurs at even higher hydrogen pressures and involves much more cracking of large molecules into smaller ones. Additional equipment is necessary to handle the significant amount of gaseous product generated, etc. Interpolating between the times allocated for the detailed design and construction of a naphtha hydrotreater and a FCC feed hydrotreater results in 6-9 months to design and 12-15 months to construct a distillate hydrotreater. Cumulatively, the two steps would take 1-1.25 years from the time at which permits were obtained.

This range is about 3 months shorter than that projected in Table 5.3-2 for the 15 ppm highway diesel fuel rule. The difference on the high end is due to the fact that 2.5 years for construction does not appear to be necessary. This estimate was reasonable in the review of progress being made towards compliance with the 2007 highway diesel fuel rule due to the extensive amount of leadtime still available. For this to be typical, all refiners planning to produce 15 ppm highway diesel fuel would already be constructing their new or revamped hydrotreaters. Clearly this is not the case, yet refiners consider themselves on track to meet the standard. Thus, the time periods resulting from an interpolation of the naphtha and FCC feed hydrotreating estimates of Table 5.3-1 appear reasonable for producing 500 ppm NRLM fuel.

Finally, both the Tier 2 gasoline rule and 15 ppm highway diesel fuel review allocated 3 months for start up for naphtha, FCC feed and highway diesel fuel hydrotreaters. Allocating the same time period for starting a distillate hydrotreater should therefore be appropriate.

Table 5.3-3 presents the results of the above assessment.

Table 5.3-3
Leadtime Projections for 500 ppm NRLM Diesel Fuel

Project Stage	Time for Individual Step	Cumulative Time
Strategic Planning	0.25-0.5	0.25-0.5
Scoping and Screening Studies	0.25-0.5	0.25-0.5
Process Design	0.5	0.75-1.0
Permitting	0.25-0.75	1.0-1.75
Detailed Engineering	0.5-0.75	1.5-2.25
Field Construction	1.0-1.25	2.0-3.0
Start-up/Shakedown	0.25	2.25-3.25

Assuming that the final rule is signed in April of 2004, this analysis indicates that some refiners should be able to produce 500 ppm NRLM fuel as early as July 2006. This coincides with the implementation of the 15 ppm highway diesel fuel cap and the ability to generate early 500 ppm NRLM credits. This analysis indicates that the last refiners should be able to produce 500 ppm NRLM fuel by July 2007. This is within a month of the implementation of the 500 ppm NRLM cap. Should any refiners be in the situation of needing this last month to produce 500 ppm NRLM fuel, they should be able to purchase early credits from other refiners and continue producing NRLM fuel until they are able to meet the 500 ppm cap.

5.3.2.4 Comparison with the 500 ppm Highway Diesel Fuel Program

The tasks refiners face in meeting the proposed 500 ppm NRLM cap is very similar to the task refiners faced with meeting the 500 ppm highway diesel fuel cap by October 1, 1993 . The primary difference is that refiners have 10 years of experience producing 500 ppm diesel fuel commercially. This should only shorten the time required to prepare for the standard relative to 1993. The 500 ppm highway diesel rulemaking was promulgated in August 1990 and took effect on October 1, 1993.[28] Thus, that rulemaking provided 3 years and two months of leadtime, nearly identical to that provided by the NRLM proposal. Some price spikes occurred with the implementation of the 500 ppm highway diesel fuel standard. However, these were almost exclusively in California, where a 10 volume percent aromatics standard was implemented at the same time. Also, the October implementation coincided with the annual increase in refiners' distillate production related to winter heating oil use. At that time, the U.S. was one of the first nation's to require 500 ppm diesel fuel, so little commercial experience was available upon which to base designs. Today, refiners and technology vendors have over 10 years of commercial experience in producing 500 ppm diesel fuel. We have also shifted the implementation date away from the peak heating oil production season. Finally, the volume of highway diesel fuel affected was more than three times that being affected by today's proposed rule, causing greater stress on the engineering and construction industries than today's proposed program would cause.

Many refiners likely to produce 500 ppm NRLM diesel fuel in 2007 also have to invest to meet the Tier 2 gasoline sulfur standards and the 15 ppm highway diesel fuel cap. However, the Tier 2 program finishes phasing in in 2006 for most refiners. The 15 ppm highway diesel fuel likewise has a 2006 implementation date. This puts them at least one year ahead of the 500 ppm NRLM standard. This minimum offset of one year should ease the burden on any specific aspect of the process (e.g., raising capital funds, design personnel, construciton personnel, etc.). The 1993 500 ppm highway diesel fuel cap also occurred in the midst of other fuel quality regulations. The phase 2 gasoline Reid vapor pressure standards and the oxygenated gasoline programs took affect in 1992, while the reformulated gasoline program began in 1995. Thus, the experience with the 500 ppm highway diesel fuel program appears to be a strong confirmation that the leadtime provided by today's proposal would be sufficient.

5.3.2.5 Small Refiners

Small refiners may need more time to comply with a sulfur control program. Small refiners generally have a more difficult time obtaining funding for capital projects, and must plan further in advance of when the funds are needed. We contracted a study of the refining industry which included assessing the time required for small refiners to obtain loans for capital investments. The simple survey revealed that small refiners would need two to three months longer than large refiners to obtain funding. If small refiners are forced to or prefer to seek funding through public means, such as through bond sales, then the time to obtain funding could be longer yet, by up to one third longer.[29] In addition, because of the more limited engineering expertise of many small refiners, the design and construction process for these refineries is relatively more difficult and time consuming. We also believe that the contractors which design and install refinery processing units will likely focus first on completing the more expensive upgrade projects for large refiners. Thus, the design and construction of desulfurization hardware for the small refiner would take longer as well. The three additional years being provided small refiners should be sufficient to compensate for these factors. This additional leadtime should provide not only enough time for these small refiners to construct equipment, but to also allow these refiners more time to select the most advantageous desulfurization technology. This additional time for technology selection will help to compensate for the relatively poor economy of scale inherent with adding equipment to a small refinery.

5.4 Feasibility of Distributing 500 ppm Sulfur Non-Highway Diesel Fuel in 2007 and 500 ppm Locomotive and Marine Diesel Fuel in 2010

There are two considerations with respect to the feasibility of distributing non-highway diesel fuels meeting the proposed 500 ppm sulfur standard. The first pertains to whether sulfur contamination can be adequately managed throughout the distribution system so that fuel delivered to the end-user does not exceed the specified 500 ppm maximum sulfur concentration. The second pertains to the physical limitations of the system to accommodate any additional segregation of product grades. These considerations are evaluated in the following Sections 5.4.3 and 5.4.4 of this Draft RIA.

5.4.1 The Diesel Fuel Distribution System Prior to the Implementation of the Proposed 500 ppm Sulfur Program:

Prior to 1993, most number 2 distillate fuel was produced to essentially the same specifications, shipped fungibly, and used interchangeably for highway diesel engines, nonroad diesel engines, locomotive and marine diesel engines and heating oil (e.g., furnaces and boilers) applications. Beginning in 1993, highway diesel fuel was required to meet a 500 ppm sulfur cap and be segregated from other distillate fuels as it left the refinery by the use of a visible level of dye solvent red 164 in all non-highway distillate. At about the same time, the IRS similarly required non-highway diesel fuel to be dyed red (to a much higher concentration) prior to retail sale to distinguish it from highway diesel fuel for excise tax purposes (dyed non-highway fuel is exempt from this tax). This splitting up of the distillate pool necessitated costly changes in the distribution system to ship and store the now distinct products separately.

In some parts of the country where the costs to segregate non-highway diesel fuel from highway diesel fuel could not be justified, both fuels have been produced to the highway specifications. Diesel fuel produced to highway specifications but used for non-highway purposes is referred to as “spill-over.” It leaves the refinery gate and is fungibly distributed as if it were highway diesel fuel, and is typically dyed at a point later in the distribution system. Once it is dyed it is no longer available for use in highway vehicles, and is not part of the supply of highway fuel. Based on the most recent EIA data, roughly 15 percent of highway fuel is spillover, representing nearly a third of non-highway consumption.

When the 15 ppm highway diesel fuel standard takes effect in 2006, an additional segregation of the distillate pool is anticipated. Since up to 20 percent of the highway diesel fuel pool is allowed to remain at 500 ppm until 2010, in some portions of the country as many as three grades of distillate may be distributed; 15 ppm highway, 500 ppm highway, and high sulfur for all non-highway uses. The final highway diesel rule estimated that 500 ppm diesel fuel would be present in 40 percent of the fungible fuel distribution system including the Northeast, parts of the Midwest and in and adjacent to the concentration of refineries in PADD 3.

5.4.2 Summary of the Proposed 500 ppm Sulfur Standards

The proposed sulfur standards generally cover all the diesel fuel that is used in mobile applications but is not already covered by the previous standards for highway diesel fuel. This fuel is defined primarily by the type of engine which it is used to power, nonroad, locomotive, and marine diesel engines. In shorthand, this fuel will be referred to as NRLM fuel.

NRLM fuels typically include:
1) Any number 1 and 2 distillate fuels used in or intended to be used in land-based nonroad, locomotive or marine diesel engines,
2) Any number 1 distillate fuel (e.g., kerosene) added to such number 2 diesel fuel, e.g., to improve its cold flow properties and

3) Any other fuel used in or blended with diesel fuel for use in nonroad, locomotive, or marine diesel engines that has comparable chemical and physical characteristics.

The proposed sulfur standards would not apply to:

1) Number 1 distillate fuel used to power jet aircraft,
2) Number 1 or number 2 distillate fuel used for other purposes, such as to power stationary diesel engines or for heating,
3) Number 4 and 6 fuels (e.g., bunker or residual fuels, IFO Heavy Fuel Oil Grades 30 and higher, ASTM DMB and DMC fuels), and
4) Any fuel used to power equipment for which a national security exemption has been approved.

As in the recent highway diesel rule, in those cases where the same batch of kerosene is distributed for two purposes (e.g., as kerosene to be used for heating and to improve the cold flow of number 2 nonroad diesel fuel), that batch of fuel would have to meet the standards being proposed today for nonroad diesel fuel. An alternative compliance approach would be to produce and distribute two distinct kerosene fuels. Under such an approach, one batch would meet the proposed sulfur standards and could be blended into number 2 NRLM diesel fuel. The other batch would only have to meet any applicable specifications for heating fuel.

We are proposing to restrict the sulfur content of NRLM fuel nationwide to no more than 500 ppm beginning in 2007. These provisions mirror controls on highway diesel fuel to 500 ppm in 1993.[30] Refiners and importers could comply with the proposed requirement by either producing NRLM fuel at or below 500 ppm, and/or by obtaining credits under the proposed averaging banking and trading (ABT) provisions. The 2007 deadline for meeting the proposed 500 ppm NRLM sulfur standard would not apply to refineries covered by special hardship provisions for small refiners. In addition, a different schedule might apply for any refineries that might be approved under the proposed general hardship provisions.

We are proposing that high sulfur NRLM diesel fuel which remains after June 1, 2007 due to the small refiner and fuel ABT provisions could be commingled with 500 ppm NRLM diesel fuel after it has been dyed to the IRS specifications until June 1, 2010. Thus, at some points in the distribution system, NRLM fuel higher than the 500 ppm standard would remain until it is precluded from production beginning June 1, 2010. The proposed 15 ppm sulfur standard for nonroad diesel fuel would take effect in June 1, 2010.

Under the proposed 500 ppm NRLM program, heating oil would be allowed to have its sulfur level remain uncontrolled; limited only by various state regulations. Thus, while NRLM is commonly distributed today with heating oil, after implementation of the proposed sulfur standards, these two grades of fuel would have to be distributed separately. To ensure that high-sulfur diesel fuel manufactured for the heating oil market would not be used in nonroad, locomotive, or marine applications, we are proposing that heating oil be injected with a fuel marker before it leaves refinery. After June 1, 2010, the fuel standards situation is simplified considerably and the fuel program structure can therefore also be simplified. We are proposing that after June 1, 2010 high sulfur diesel fuel no longer be permitted to be used in any NRLM equipment. The only high sulfur distillate remaining in the market should be heating oil. Heating oil would have to be kept segregated and preventing its use in NRLM equipment could be enforced on the basis of sulfur level, avoiding the need for a unique marker to be added to heating oil. Thus, we are proposing that the marker requirement for heating oil expire after June 1, 2010.

After June 1, 2010, we are proposing that locomotive and marine diesel fuel would be allowed to remain at the 500 ppm level. Under the proposed small refiner hardship and fuel credit provisions, we would also allow the continued production and use of 500 ppm nonroad diesel fuel for a limited time past June 1, 2010. To ensure that adequate quantities of 15 ppm diesel are produced, we are proposing the use of a marker to segregate locomotive and marine diesel fuel from 500 ppm nonroad diesel fuel beginning June 1, 2010. Since use of the marker in heating oil is no longer required, we are proposing that the same marker used for heating oil from June 1, 2007 through 2010 be the marker used in locomotive and marine diesel fuel beginning June 1, 2010. We propose that the marker would be required to be added at the refinery gate just as visible evidence of the red dye is required today, and fuel containing the marker would be prohibited from use in any nonroad application.

Beginning June 1, 2014, after all small refiner and credit provisions have ended, the 500 ppm locomotive and marine standard could be enforced based on sulfur level throughout the distribution system and at the end-user. Therefore, there would no longer be any need for a marker. Consequently, we are proposing that after May 31, 2014 there would be no marker requirement and the different grades of fuel, 15 ppm, 500 ppm, and high sulfur would merely have to be kept segregated in the distribution system.

We are proposing that the current requirement that non-highway distillate fuels be dyed at the refinery gate be made voluntary effective June 1, 2006. The IRS requirement that non-highway fuel be dyed prior to sale to consumers to exempt it from excise taxes will still apply.

There are two considerations with respect to the feasibility of distributing non-highway diesel fuels meeting the proposed 500 ppm sulfur standard. The first pertains to whether sulfur contamination can be adequately managed throughout the distribution system so that fuel delivered to the end-user does not exceed the specified 500 ppm maximum sulfur concentration. The second pertains to the physical limitations of the system to accommodate any additional segregation of product grades. These considerations are evaluated in the following Sections 5.4.1 and 5.4.2 of this Draft RIA.

5.4.3 Limiting Sulfur Contamination

With respect to limiting sulfur contamination during distribution, the physical hardware and distribution practices for non-highway diesel fuel do not differ significantly from those for current highway diesel fuel. Therefore, we do not anticipate any new issues with respect to limiting sulfur contamination during the distribution of non-highway fuel that would not have already been accounted for in distributing highway diesel fuel. Highway diesel fuel has been required to meet a 500 ppm sulfur standard since 1993. Thus, we expect that limiting contamination during the distribution of 500 ppm non-highway diesel engine fuel can be readily accomplished by industry.

5.4.4 Potential Need for Additional Product Segregation

During the first step of today's program, we anticipate that 500 ppm non-highway diesel engine fuel would be distributed in fungible batches with 500 ppm highway diesel fuel through the distribution system to the terminal level. When the second step of the proposed program would require nonroad diesel fuel to meet a 15 ppm sulfur standard all highway fuel would also be required to meet a 15 ppm standard. Thus a large fraction of the potential 500 ppm diesel fuel pool would disappear. Since marked 500 ppm locomotive and marine diesel fuel would be a relatively small volume product, we anticipate that in most parts of the distribution system it would not be carried as a separate product in the fungible distribution system. Therefore we anticipate that most shipments of 500 ppm locomotive and marine fuel would be from refinery racks or other segregated shipments directly into end-user tankage. Any diesel fuel supplied off the fungible supply system for locomotive and marine uses would therefore likely be spillover from 15 ppm supply.

The proposed non-highway sulfur program would require the use of a unique fuel marker in heating oil to differentiate it from other non-highway diesel engine fuels that would be subject to today's proposed sulfur standards. Under the proposed program, heating oil would be injected with a marker at the refinery and segregated throughout the fuel distribution system to the end-user. The heating oil marker requirement would expire after 2010, to be replaced with the requirement that 500 ppm diesel fuel destined for locomotive and marine use contain the marker previously used in heating oil. The presence of the marker raises the potential for additional product segregation needs in both 2007 and 2010.

The proposed application of different sulfur standards to portions of the non-highway distillate pool based on end-use also raises concerns regarding the potential need for additional product segregation.

Currently, distillate fuel for all non-highway uses is typically drawn from a single pool that meets the most stringent specifications for any non-highway use. For example, it is our understanding that nearly all heating oil meets the cetane specification for non-highway diesel engine use despite the lack of applicability of a cetane specification for distillate fuel used as heating oil. This is because fuel manufactures and marketers have found that the potential savings from manufacturing a low cetane heating oil are typically outweighed by the additional costs of segregating an additional heating-oil-only product throughout the distribution system.

We anticipate that the significant cost of desulfurizing non-highway diesel engine fuel to meet today's proposed sulfur standards would provide a strong incentive for the fuel distribution system to evaluate whether the additional costs of distributing non-highway distillate fuels of different sulfur specifications is economically justified. This situation is analogous to that faced by industry after the implementation of the current EPA requirement in 1993 that highway diesel fuel have a sulfur content of less than 500 ppm.

The Internal Revenue Service (IRS) requirement that diesel fuel used in non-highway engines be dyed before it leaves the terminal to indicate its non-taxed status also raises concerns about the potential need for additional product segregation under the proposed NRLM sulfur program. Fuel that meets highway diesel specifications but is destined for the non-highway market can leave the terminal undyed provided that the tax is payed. Non-highway users of such fuel can then apply to the federal and applicable state revenue offices for a refund of the highway taxes payed on the fuel. In areas of the country where only 500 ppm diesel fuel is currently available by pipeline, most bulk plant operators nevertheless maintain dual tankage for dyed and undyed 500 ppm diesel fuel to meet the demands of their customers for highway-tax-free non-highway diesel fuel. Such bulk plant operators currently receive dyed diesel fuel by truck from local refineries. Thus, the IRS non-highway diesel dye requirement may result in a strong incentive for parties in the fuel distribution system downstream of the terminal to maintain segregated pools of undyed highway and dyed non-highway diesel fuel that differ in no other respect than the presence of dye (both after the implementation of the 15 ppm highway diesel requirements in 2007, and the proposed requirements for NRLM fuel).

We expect that after the implementation of the proposed NRLM standards most bulk plant operators would request that the terminal (or refinery rack) dye 500 ppm fuel destined for sale into the non-highway market, so that they continue their current practice of offering untaxed diesel to their non-highway customers. This raises issues of available tankage.

The following discussion evaluates the potential need for additional product segregation for each segment of the distribution system from the refinery through to the end-user due to the implementation of the proposed 500 ppm non-highway diesel sulfur standard.

Refineries:

Due to economies of scale involved in desulfurization, we expect that most individual refineries would choose to manufacture a single or perhaps in some case two sulfur grades of diesel fuel. We do not anticipate that individual refineries would produce substantial quantities of all the different diesel fuel sulfur grades (15 ppm highway fuel, 500 ppm, and heating oil). We do not anticipate the need for additional product segregation at refineries. As discussed above, today’s proposal would allow highway and nonroad diesel fuels to be shipped fungibly until NRLM fuel is dyed for IRS excise tax purposes. Therefore, today’s proposed sulfur standards for NRLM diesel fuel would not require refiners to put in new product storage tanks to handle these fuels. The proposed marker requirements for heating oil from 2007-10 and for locomotive and marine diesel fuel from 2010-14 would also not cause the need for additional product segregation at the refinery. We expect that refiners would inject the marker into the fuel stream as it leaves their facility. Since the dye requirement for these fuels is removed at the refinery gate, they should be able to modify their existing additive injection hardware to satisfy this need. The ability of a refinery to sell diesel fuel directly from the would mean that they could market dyed and marked fuel with out the need for additional tankage. The dye and marker could be injected as the fuel is loaded into the tank truck from the rack.

A limited number of refiners would be allowed to produce high-sulfur NRLM until 2010. We expect that such fuel would be distributed via segregated means from the refinery to the end-user. Thus, we do not expect that such fuel would result in the need for additional tankage.

There will be no physical differences between 500 ppm highway and 500 ppm NRLM produced by refiners. The distinction between the two fuels is only made for accounting purposes to ensure compliance with limitations on the volume of 500 ppm highway diesel fuel that can be produced by refiners (under the highway diesel final rule) is complied with.

Pipelines:

Under today's proposal, pipeline operators would ship only a single 500 ppm diesel fuel to be later directed to either the highway or NRLM market. We project that only the 40 percent of pipelines that the highway diesel rule projected would carry 500 ppm highway diesel fuel would be the pipelines that elect to 500 ppm diesel fuel after the implementation of the proposed NRLM diesel fuel program. Therefore, we do not expect that the proposed 500 ppm sulfur standards would necessitate the need for additional product segregation in the pipeline distribution system.

There is no physical separation between product batches shipped by pipeline. When the mixture that results at the interface between two products that touch each other in the pipeline can be cut into the one of these products, it is referred to as product downgrade. When the mixture must be removed for reprocessing, it is referred to as transmix. Given that the pipelines that carry 500 ppm diesel fuel would be able to combine batches of 500 ppm non-highway diesel fuel with batches of 500 ppm highway diesel fuel, we do not expect that today's program would result in an increase the volume of product downgrade or transmix volumes. To the contrary, there may be some opportunity for improved efficiency because of the increase in batch sizes shipped by pipeline. This potential benefit could be significant given that the volume of 500 ppm NRLM shipped by pipeline would represent a sizeable fraction of the total 500 ppm diesel fuel volume.

We also do not expect that the marker requirement for heating oil would result in an increased need for product segregation in the pipeline or an increase in product downgrade or transmix volumes. After the implementation of the proposed 500 ppm standard for nonroad, locomotive, and marine fuel, we project that significant volumes of heating oil would continue to be present only in the fuel distribution system that supplies the Northeast, limited adjoining parts of the Midwest, and the Pacific Northwest.

We believe that only in these areas, would the demand for heating oil be sufficiently large to justify the continued distribution of high-sulfur diesel fuel once nonroad, locomotive, and marine diesel fuel is removed from the potential high-sulfur diesel pool. Therefore, heating oil would not be present in pipeline systems that supply areas outside of the Northeast, limited adjoining parts of the Midwest, and the Pacific Northwest. The pipelines that we project would handle heating oil after the implementation of today's proposal are those that we projected would also be carrying 500 ppm highway diesel fuel from 2006-10. Therefore, these pipelines would already have facilities to also carry 500 ppm NRLM in 2007 (in the pipeline there is no physical distinction between 500 ppm highway and 500 ppm NRLM diesel fuel). Consequently, we do not expect that the heating oil marker requirement would result in additional product segregation by pipeline.

We anticipate that in some cases high sulfur fuel will be sold directly from refinery racks throughout the country. In addition, some terminals outside of these areas may market limited quantities of high-sulfur diesel fuel that was generated in the pipeline during the distribution of 15 ppm diesel fuel. We expect that such fuel would be marketed directly from the terminal to the end user. The limited additional tankage at the terminal was accounted for under the highway program.

The situation for pipeline operators after 2010 when the marker must be used in locomotive and marine fuel would be somewhat different, but is still not expected to result in any new product segregation needs. Under today's proposal, all nonroad diesel fuel would be required to meet a 15 ppm sulfur standard in 2010 except for limited quantities of small refiner and credited fuel that could remain at 500 ppm for a limited additional time. We expect that this nonroad fuel which remains at 500 ppm after 2010 would be distributed by the refiner to the end-user directly. Therefore, its presence in the distribution system would not result in the need for additional product segregation. The highway diesel program also requires that all highway diesel fuel meet a 15 ppm sulfur standard beginning in 2010. Consequently, the only 500 ppm diesel fuel possibly remaining in the fungible distribution system would be marked 500 ppm locomotive and marine diesel fuel. We expect that pipelines that carried 500 ppm diesel fuel prior to 2010 would be the only pipelines that might choose to carry marked 500 ppm locomotive and marine diesel fuel. Therefore, the equipment that had been used to handle unmarked 500 ppm diesel fuel prior to 2010 would be switched to handling marked 500 ppm diesel fuel after 2010. Due to the reduction in the total potential 500 ppm diesel pool beginning in 2010, it is likely that a number of pipelines will no longer find it economical to carry 500 ppm as well as 15 ppm diesel fuel. We are projecting that most pipelines would elect not to carry 500 ppm diesel fuel and would carry only 15 ppm diesel fuel after 2010. This could result in some overall simplification of the diesel distribution system. Another factor that mitigates any potential need for additional product segregation as a result of the marker requirement for locomotive and marine diesel fuel is that locomotive and marine diesel fuel is often distributed through a segregated distribution system.[I] Based on the above discussion, we anticipate that the locomotive and marine diesel fuel marker requirement would not result in an increased need for product segregation in the pipeline or an increase in product downgrade or transmix volumes.

[I] In addition, we understand that marine diesel fuel is often shipped by barge from the refiner to the end user. This is also the case for locomotive diesel fuel when there is an opportunity for waterborne transportation.

Terminals:

The product segregation needs at terminals are directly affected by the range of products that they receive by pipeline. Thus, the discussion regarding the potential impacts of today's proposed rule on terminal operators closely parallels the preceding discussion on the potential impacts on pipeline operators. The proposed allowance that highway and non-highway diesel fuel meeting the same sulfur specification could be shipped fungibly until non-highway diesel fuel must be dyed to indicate its non-tax status obviates the need for additional product segregation at the terminal that might otherwise result from today's proposed sulfur standards. We expect that terminal operators would store non-highway and highway diesel fuel meeting the same sulfur specification in the same tank.

We do not anticipate that the proposed marker requirement for heating oil would require any additional storage tanks. As discussed above, in most of the country, we do not anticipate heating oil would continue to be carried as a separate grade in the fungible distribution system after the implementation of the proposed NRLM sulfur standards. As a result, 500 ppm fuel could take the place of the current tank of high sulfur fuel. In the areas where we project heating oil would continue to be distributed, 500 ppm highway fuel is also projected to be distributed. Consequently, marked heating oil can remain in its high sulfur tank, and the existing 500 ppm highway tank can service both highway and NRLM uses.

Bulk Plants:

Bulk plants are secondary distributors of refined petroleum products. They typically receive fuel from terminals and distribute fuel in bulk by truck to end users. Consequently, while for highway fuel, bulk plants often serve the role of a fuel distributor, delivering fuel to retail stations, for nonroad fuel, they often serve the role of the retailer, delivering fuel directly to the end-user. Bulk plants represent the one point in the distribution system where we anticipate some additional tankage would likely be added as a result of today's proposal. However, we project that only a small subset of the bulk plants would be faced with the choice of adding additional tankage. In most areas of the country, a distinct grade of heating oil would no longer be carried, and bulk plant operators could simply switch the tank that they previously devoted to high sulfur service to 500 ppm NRLM and heating oil service in 2007.

In areas where heating oil is anticipated to remain as a separate grade, we anticipate that bulk plants will face the choice of adding a new tank and perhaps demanifolding their delivery truck in order to distribute dyed 500 ppm NRLM diesel fuel in addition to dyed and marked heating oil. In this context demanifolding refers to the process of separating a single storage tank on a delivery tank truck to make two compartments. Some bulk plants that face the choice of installing the facilities to allow additional product segregation may find the cost of a new storage tank and demanifolding their delivery truck is too high, or may not have the space or capability to add new tank. However, such bulk plants would have other options. If they own another bulk plant facility in the area, they may choose to optimize use of available tankage by carrying one of the grades at each facility. Even if they do not own another facility, they may be able to work out a similar arrangement with a terminal or other bulk plant in the area. They could choose to supply heating oil only during the winter months, and supply NRLM during the summer months to both markets. Finally, they could simply choose not to distribute one of the fuel grades. (For example, either sell NRLM for both uses or sell only heating oil and allow other fuel distributors in the area to satisfy the NRLM market.) We anticipate that approximately 1,600 bulk plants would face the decision of adding new tankage or finding some other means of continuing to serve both heating oil and nonroad markets. This is the number of bulk plants that we project would be located in the areas of the country where heating oil would be continued to be carried by the fungible distribution system after the implementation of the proposed NRLM standards and where 500 ppm fuel would also be carried. Of these, we expect no more than 1,000 would choose to install a new tank.[31]

We do not anticipate that bulk plants would invest to carry locomotive and marine fuel as a separate grade in 2010. Therefore, unless a bulk plant had existing tankage available or supplied a majority of its fuel to locomotive and marine uses, this grade would likely be limited to refinery and terminal distribution. This is how the bulk of the distribution of locomotive and marine diesel fuel occurs today.

Based on the above discussion, we believe that the potential impacts of today's proposed rule on the distribution system due to the need for additional product segregation would be minimal and easily accommodated by industry. Please see 7.3 of this Draft RIA for a discussion of the increased distribution costs associated with the need for additional segregation at bulk plants.

5.5 Feasibility of Producing 15 ppm Sulfur Nonroad Diesel Fuel in 2010

5.5.1 Expected use of Desulfurization Technologies for 2010

Like the 500 ppm sulfur standard for 2007, we considered a number of different criteria to project which desulfurization technologies which would be used to comply with a 15 ppm nonroad sulfur cap standard for 2010. The criteria we considered included: 1) the time which refiners will have to choose a new technology, 2) whether the technology would be available for 2010 and if the technology is available, how proven it is, 3) whether the technology is cost-competitive by comparing it to other technologies, 4) whether the technology is available from an industry-trusted vendor which has proven itself to the industry by providing other successful refining technologies, particularly if the vendor has proven itself in the U.S., and 5) whether the vendor has the capability to meet the demands of the industry.

Unlike the 2007 standard, refiners would have plenty of time to evaluate the various desulfurization technologies and to choose which one would be best suited for their particular application. As stated above, we believe that this rule would be promulgated sometime in early 2004, thus, refiners will have 6 years between when the rule is promulgated and when the rule takes effect. Therefore, refiners would not be constrained in any way when making their decisions so this particular issue did not figure into our choice of the technologies which they would use.

Next, we considered whether a technology would be expected to be available for 2010. Of course, conventional hydrotreating is available as it has been used in a number of applications to comply with a very stringent sulfur standard like a 15 ppm sulfur standard as described above. In addition, many refiners are expected to use conventional hydrotreating to comply with the highway diesel 15 ppm cap which applies in 2006. This would give refiners some experience with this technology prior to making a decision on what technology to use. Phillips is targeting to have their diesel fuel commercial demonstration unit up and running in early 2004 and they are expecting to have numerous gasoline desulfurization units starting up in 2004 as well. The operation of these units for two or more years prior to having to make their decisions for 2010 would give refiners confidence that these units can operate effectively over a significant period of time.

Linde already has a diesel fuel hydrotreating commercial demonstration unit operating which is a revamp of a 500 ppm highway diesel fuel desulfurization unit (installed before the existing highway hydrotreater). This unit demonstrates that the technology does indeed work for treating untreated diesel fuel to 500 ppm, however, refiners would like to see the technology demonstrated over the 500 ppm to 15 ppm sulfur reduction interval as well. With the 15 ppm highway diesel fuel sulfur standard taking effect in 2006, Linde should be able to demonstrate its technology for the 500 ppm to 15 ppm sulfur reduction interval. Thus, refiners that would be seeking to comply with the proposed 15 ppm sulfur nonroad standard should be able to see at least one, and probably more, examples of the Linde Isotherming process operating to desulfurize diesel fuel down to 15 ppm.

The oxidation and extraction technologies by Petrostar and Unipure do not have units operating now, but are projecting to have commercial demonstration units operating by 2006. However, an oxidation and extraction unit which begins operation in 2006 would not provide two years of operations for interested nonroad refiners prior to when they will have to choose their technology for 2010. Similarly, biodesulfurization is not expected to have a commercial demonstration unit operating before 2006.

Another issue which refiners would consider is the cost of installing and operating these various technologies. Biodesulfurization has not yet developed detailed desulfurization costs for their process. Of the oxidation and extraction technologies, Unipure did provide us with desulfurization cost information based on testing at their laboratory, and that information shows that it might be cost competitive with conventional hydrotreating. Petrostar, however, has not yet provided us with desulfurization information. Phillips also has provided us with diesel fuel desulfurization cost information from their pilot plant which is backed up by the success which they have had with their commercial gasoline desulfurization unit (see Chapter 7.2). That technology seems to be less expensive than conventional hydrotreating, it appears to be suited primarily for desulfurizing low sulfur diesel fuel down to very low sulfur values rather than for desulfurizing higher sulfur feedstocks. As a result, its primary usefulness would be for refiners revamping from compliance with 500 ppm in 2007 to 15 ppm in 2010. Finally, Linde provided us diesel fuel desulfurization cost information which is based on their pilot plant and their engineering cost estimates for the commercial demonstration unit at the Giant refinery. The Linde process seems to be less expensive than conventional hydrotreating and is capable of desulfurizing high sulfur feedstocks down to 15 ppm (see Chapter 7.2).

We next evaluated whether each diesel fuel desulfurization technology vendor is equipped to provide preliminary engineering and support the installations of its technology to a significant part of the refining industry. Conventional hydrotreating is provided by numerous vendors (Akzo Nobel, Criterion, Haldor Topsoe, IFP, and UOP) the majority of which manufacture their own line of diesel desulfurization catalysts. Also, these vendors supported the installation of many diesel fuel hydrotreaters to meet the 500 ppm highway diesel fuel sulfur standard which went into effect in 1993, and will be working with refiners to meet the very stringent 15 ppm highway diesel fuel sulfur standard which begins to take effect in 2006. Thus, conventional desulfurization technology is poised to make a significant contribution.

Phillips licenses several different technologies to refiners now, including its S-Zorb gasoline desulfurization technology and an alkylation technology, and has licensed refining technologies for over 60 years. Phillips has a robust research and development staff and also an engineering staff to support the licensing of its S-Zorb technology.

Linde licenses several different technologies now including sulfur and olefins recovery, natural gas processing, hydrogen production, reforming, air separation, and of course the Isotherming process for desulfurizing diesel fuel. Linde has a large engineering and design department which has been active for over 30 years, and now Linde has an alliance with Roddy Engineering for additional engineering support. Thus, Linde is capable of supporting its desulfurization technology for a significant penetration into the U.S. refining industry.

The oxidation and extraction technologies are being developed by two separate entities, one being Unipure and the other Petrostar. Unipure is associated with Texaco and Mustang engineering. Thus, Unipure potentially has both research and development and engineering support for its technology. Petrostar is affiliated with DeGussa Catalysts which can provide research and development support. Neither of these technologies have yet been licensed for desulfurizing diesel fuel.

After evaluating the various criteria for each technology and comparing across technologies, we developed a projection for the mix of technologies which would be used in 2010 for complying with the 15 ppm cap standard. Since refiners will have plenty of time to sort through the various technologies, we believe that the leadtime issue would have no bearing on refiners ability to choose an advanced desulfurization technology. Whether a technology will have accumulated at least two years of commercial experience is an important issue for the oxidation and extraction and biodesulfurization technologies as these technologies have not announced that their technology is available for licensing yet, and are not expected to have a commercial demonstration unit operating for at least two years. Thus, while the Petrostar, Unipure desulfurization technologies might be selected by refiners for 2010, we are not including their technologies in our projected mix of technologies.

This leaves conventional hydrotreating, Phillips S-Zorb and Linde Isotherming. Obviously, conventional hydrotreating will have the most refining experience due to refiners' experience earlier on and also due to production of 15 ppm highway fuel for 2006. However, both S-Zorb and Isotherming are expected to have one or more diesel fuel desulfurization commercial demonstration units operating for over two years. Both the S-Zorb and the Isotherming hydrotreating processes are expected to be lower in cost than conventional hydrotreating providing a strong incentive to refiners which are seeking to lower their refining margins. Also both Phillips and Linde have research and development and engineering capacity to support their processes, although not the same level of support as the multiple conventional hydrotreating firms. After comparing these various criteria, we decided that the lower cost of S-Zorb and Isotherming would be the most important driver for these technologies. Thus, we believe that S-Zorb and Isotherming would each be used to a greater extent than conventional hydrotreating. We project that S-Zorb and Isotherming would each capture 40 percent of the nonroad desulfurization market by 2010, while conventional hydrotreating would capture the remaining 20 percent of the nonroad desulfurization market.

It was also necessary to estimate the technology mix for other potential years for a 15 ppm sulfur cap standard per the various other alternative fuel options being considered. The relative cost of these technologies is not estimated to change, however, the degree to which refiners have confidence in each of these technologies would change over time. In the years before 2010, refiners would not be expected to place as much trust with S-Zorb and Isotherming because there would be less time for these technologies to be proven to refiners. In 2009 we project that S-Zorb and Isotherming would each capture 30 percent of the nonroad desulfurization market. Similarly, we project that S-Zorb and Isotherming each capture 20 percent of the nonroad desulfurization market in 2008. For 2010, we project that S-Zorb and Isotherming would each capture 40 percent of the desulfurizaiton market. Finally, in 2012 and later, we project that S-Zorb and Isotherming would each capture 50 percent of the nonroad desulfurization markets.

5.5.2 Leadtime Evaluation

More leadtime would be required to meet a 15 ppm diesel fuel cap than a 500 ppm cap. The additional time would primarily involve the scoping and screening step, as the technology to achieve a 15 ppm sulfur cap is just being demonstrated on a commercial scale and a number of advanced technologies promising lower costs are under development. This additional time might be on the order of a few months, while the 2010 implementation date for the 15 ppm cap provides an additional three years of leadtime. Therefore, the amount of leadtime available for the 15 ppm cap on nonroad diesel fuel should be more than sufficient for refiners to prepare for producing this fuel.

Of more interest is the interaction between the timing of the 15 ppm cap on highway diesel fuel and that proposed for nonroad diesel fuel. The time periods listed in Table 5.3-3 indicate that refiners would have to start their process designs 2.0-2.75 years before first producing 15 ppm diesel fuel and complete these process designs 1.5-2.25 years before the implementation date. This means that process design should begin by September 1, 2007 to June 1, 2008, and be completed by March 1 to December 1, 2008. This would provide refiners planning to produce 15 ppm nonroad diesel fuel with 15-24 months of experience by highway diesel fuel refiners before initiating their process design. Given that catalyst cycles last 2-3 years, refiners could observe the performance of catalysts used to produce 15 ppm highway diesel fuel for one half to two thirds of a full cycle before having to begin their process design for nonroad While most of the units producing highway diesel fuel in 2006 are expected to use conventional hydrotreating, as discussed above, we also expect both Linde Isotherming and Phillips' SZorb processes to be used to commercially produce 15 ppm diesel fuel by the end of 2004. Thus, refiners planning for 2010 would be able to observe these newer processes for more than 3 years prior to their selection of vendor and technology. This should be sufficient to overcome any uncertainty about their performance. Overall, the available leadtime should allow all refiners to take advantage of the operating performance of the highway units and minimize their costs.

5.6 Feasibility of Distributing 15 ppm Sulfur Nonroad Diesel Fuel in 2010

The same two criteria apply regarding the evaluation of the feasibility of distributing 15 ppm sulfur nonroad diesel fuel as apply regarding the feasibility of distributing 500 ppm sulfur non-highway diesel fuel: limiting sulfur contamination, and the potential need for additional product segregation. However, concerns related to limiting contamination during the distribution of 15 ppm nonroad diesel fuel are more substantial given that industry is just now in the process of learning how to accomplish the task of distributing 15 ppm diesel fuel in the fungible distribution system in preparation for compliance with the 15 ppm sulfur specification for highway diesel fuel in 2007. These considerations are evaluated in the following 5.6.3 and 5.6.4 of this Draft RIA.

5.6.1 The Diesel Fuel Distribution System Prior to the Implementation of the Proposed 15 ppm Nonroad Diesel Sulfur Program

Refer to 5.4 of this Draft RIA for a discussion of the diesel fuel distribution system prior to the implementation of the proposed 500 ppm NRLM sulfur program. Section 5.4 also contains a discussion of the potential effects on the distribution system of the implementation of the 500 ppm NRLM program in 2007 and the continuance of the 500 ppm sulfur standard for locomotive and marine diesel fuel past 2010. The discussion in section 5.4 provides the baseline against which the potential effects on the distribution system from the implementation of the proposed 15 ppm nonroad diesel sulfur standard in 2010 are evaluated.

5.6.2 Summary of the Proposed 15 ppm Nonroad Diesel Sulfur Standard

We are proposing to restrict the sulfur content of nonroad diesel fuel nationwide to no more than 15 ppm beginning in 2010. This proposed requirement mirrors the 15 ppm sulfur requirement for highway diesel fuel which will become effective in 2006.[32] As with the 500 ppm NRLM standard that we are proposing, refiners and importers could comply with the proposed 15 ppm nonroad standard by either physically producing 15 ppm fuel or by obtaining sulfur credits. Also similar to the proposed 500 ppm NRLM standard, the deadlines for meeting the 15 ppm nonroad sulfur standard would not apply to refineries covered by special hardship provisions for small refiners. In addition, a different schedule might apply for any refineries that might be approved under the proposed general hardship provisions. Only 15 ppm diesel fuel would be permitted for use in 2011 and later model year nonroad equipment. As discussed in 5.4, locomotive and marine diesel fuel would continue to be subject to the proposed 500 ppm sulfur standard after 2010.

In order to allow for a smooth and orderly transition of diesel fuel in the distribution system to 15 ppm, we are proposing that parties downstream of the refineries be allowed a small amount of additional time to turnover their tanks to 15 ppm. We are proposing that at the terminal level, nonroad diesel fuel would be required to meet the 15 ppm sulfur standard beginning July 15, 2010. At bulk plants, wholesale purchaser-consumers, and any retail stations carrying nonroad diesel, this fuel would have to meet the 15 ppm sulfur standard by September 1, 2010. The proposed transition schedule for compliance with the 15 ppm standard at refineries, terminals, and secondary distributors are the same as those allowed under the recently promulgated highway diesel fuel program.

5.6.3 Limiting Sulfur Contamination

In the highway diesel rule, EPA acknowledged that meeting a 15 ppm sulfur specification would pose a substantial new challenge to the distribution system. Refiners, pipelines and terminals would have to pay careful attention to and eliminate any potential sources of contamination in the system (e.g., tank bottoms, deal legs in pipelines, leaking valves, interface cuts, etc.) In addition, bulk plant operators and delivery truck operators would have to carefully observe recommended industry practices to limit contamination, including things as simple as cleaning out transfer hoses, proper sequencing of fuel deliveries, and parking on a level surface. The necessary changes to distribution hardware and practices and the associated costs are detailed in the RIA to the highway diesel final rule.[33]

We are continuing to work with industry to ensure a smooth transition to the 15 ppm sulfur standard for highway diesel fuel. In November of 2002, a joint industry EPA Clean Diesel Fuel Implementation Workshop was held in Houston, Texas. This workshop was sponsored by a broad cross-section of trade organizations representing the diesel fuel producers and distributors who will be responsible for compliance with the 15 ppm highway diesel standard: the National Petroleum Refiners Association (NPRA), the Association of Oil Pipelines (AOPL), the Independent Fuel Terminal Operators Association (IFTOA), the National Association of Conveniences Stores (NACS), the Society of Independent Gasoline Marketers of America, and the Petroleum Marketers Association of America (PMAA). The workshop featured over 20 presentations by industry the topic of distributing 15 ppm diesel fuel, as well as a questions and answers discussion.[34] Some of these presentations contained the results of the first test programs conducted by the pipeline industry to develop procedures and identify the changes needed to limit sulfur contamination. These initial test programs did not resolve all of industry’s concerns related to the ability to limit sulfur contamination during the distribution of 15 ppm diesel fuel. However, the results were promising and indicated that with further testing and development the distribution industry can successfully manage sulfur contamination during the distribution of 15 ppm diesel fuel. We understand that the fuel distribution industry is in the process of conducting such additional work and that there are plans to develop standard industry practices for each segment of the distribution industry to limit sulfur contamination. We will keep abreast of developments in this area.

Due to the need to prepare for compliance with the highway diesel program, we anticipate that issues related to limiting sulfur contamination during the distribution of 15 ppm nonroad diesel fuel will be resolved well in advance of the proposed 2010 implementation date for nonroad fuel. We are not aware of any additional issues that might be raised unique to nonroad fuel. If anything we anticipate limiting contamination will become easier. We expect that 15 ppm nonroad diesel fuel will be distributed in fungible batches with 15 ppm highway diesel fuel up to the point when it leaves the terminal and nonroad diesel fuel must be dyed per IRS requirements. The resulting larger batch sizes as a percentage of the total 15 ppm diesel throughput may make it somewhat easier to limit sulfur contamination and could reduce losses to product downgrade during transportation by pipeline. We also expect that the projected disappearance of heating oil from much of the distribution system outside of the North East, adjoining parts of the Midwest, and North West would tend to lessen the opportunity for sulfur contamination.

We do not anticipate that there would be a substantial increase in the number of off-specification 15 ppm diesel fuel batches in the distribution system due to sulfur contamination. To the extent that there are off-specification batches of nonroad (and highway) diesel fuel, the 500 ppm locomotive and marine diesel fuel markets could provide a market for off-spec product that could be important to during the transition to 15 ppm nonroad diesel fuel in 2010.

5.6.4 Potential need for Additional Product Segregation Due to the Implementation of the Proposed 15 ppm Sulfur Specification for Nonroad Diesel Fuel

Two of the three factors discussed in 5.4 of this Draft RIA regarding the potential need for additional product segregation due to the implementation of the proposed 500 ppm NRLM standard in 2007 also apply with respect to the potential impact of the proposed 15 ppm standard for nonroad diesel fuel in 2010: 1) the application of a different sulfur standard to a portion of the non-highway distillate pool based on end-use, and 2) the Internal Revenue Service (IRS) requirement that diesel fuel used in non-highway engines be dyed prior to sale to consumers to indicate its non-taxed status before it leaves the terminal. The potential impact on product segregation of the proposed marker requirement was discussed in 5.4of this Draft RIA within the context of the proposed 500 ppm sulfur specification for NRLM fuel in 2007 and for locomotive and marine diesel fuel in 2010.   The implementation of the proposed 15 ppm sulfur standard would not alter the conclusions we reached in 5.4 regarding the potential impacts on the proposed marker requirements

The following discussion evaluates the potential need for additional product segregation in each segment of the distribution system from the refinery through to the end-user due to the implementation of the proposed 15 ppm sulfur standard for nonroad diesel fuel.

Refineries:

Due to economies of scale involved in desulfurization, we expect that most individual refineries would choose to manufacture a single or perhaps in some case two sulfur grades of diesel fuel. We do not anticipate that individual refineries would produce substantial quantities of all the different sulfur grades (15 ppm, 500 ppm locomotive and marine, and heating oil). We do not anticipate the need for additional product segregation at refineries. As discussed above, we do not anticipate that there would be any physical differences between 15 ppm manufactured for the highway market and 15 ppm diesel fuel manufactured for the non-highway market. Today's proposal would allow 15 ppm diesel fuels intended for the highway and nonroad markets to be shipped fungibly until NRLM fuel is dyed for IRS excise tax purposes. Therefore, today's proposed 15 ppm sulfur standards for nonroad diesel fuel would not require refiners to put in new product storage tanks.

A limited number of refiners would be allowed to produce 500 ppm nonroad diesel fuel until 2010. However, we expect that such fuel would be distributed via segregated means from the refinery to the end-user. Thus, we do not expect that such fuel would result in the need for additional tankage.

Pipelines:

Under today's proposal, pipeline operators would ship only one 15 ppm diesel fuel. Therefore, we do not expect that the proposed 15 ppm nonroad diesel sulfur standards would necessitate the need for additional product segregation in the pipeline distribution system (i.e. there would be no increase in the number of different diesel fuel grades carried by the pipeline system relative to 2007). Due to the large reduction in the potential 500 ppm diesel pool that would accompany the implementation of the proposed 15 ppm nonroad diesel sulfur standard, we expect that 500 ppm diesel fuel would all but disappear from the fungible pipeline distribution system. This could result in a simplification of in the number of fuel grades carried in certain parts of the fungible distribution system.

We also project that today's program would not result in an increase the volume of product downgrade or transmix. To the contrary, similar to the situation associated with shipping batches of 500 ppm diesel fuel by pipeline until 2010, there may be some opportunity for improved efficiency (i.e. a reduction in downgrade and transmix volumes) because of the increase in 15 ppm batch sizes shipped by pipeline.

Terminals:

Under the proposed sulfur program we expect that terminal operators would maintain storage facilities for a single 15 ppm diesel fuel. Only when 15 ppm fuel leaves the refinery would it be segregated into two distinct products due the addition of dye to nonroad diesel fuel per the IRS requirements to indicate its non-taxed status. Therefore, we do not expect that the implementation of the proposed 15 ppm nonroad sulfur standard would result in the need for additional product segregation at terminals.

Bulk Plants:

When the 15 ppm standard for nonroad diesel fuel would be implemented in 2010, we expect that bulk plant operators would switch the tank that previously contained 500 ppm NRLM to dyed 15 ppm nonroad service in 2010.[35] Therefore, we do not anticipate the need for additional product segregation at bulk plants due to the implementation of the proposed 15 ppm nonroad sulfur specification.

5.7 Impacts on the Engineering and Construction Industry

An important aspect of the feasibility of any fuel quality program is the ability of the refining industry to design and construct any new equipment required to meet the new fuel quality standard. In this section we assess the impact of the proposed NRLM fuel program on engineering design and construction personnel needs. Specifically, we focus on three types of workers: front-end designers, detailed designers and construction workers needed to design and build new desulfurization equipment. In doing this, we consider the impacts of the Tier 2 gasoline sulfur and the 2007 highway diesel sulfur programs on these same types of personnel. standard and the proposed nonroad diesel sulfur programs. We compare the overall need for these workers to estimates of total employment in these areas. In general, it would also be useful to expand this assessment to specific types of construction workers which might be in especially high demand, such as pipe-fitters and welders. However, estimates of the number of people currently employed in these job categories are not available. Thus, it is not possible to determine how implementing the nonroad diesel fuel sulfur cap and other programs might stress the number of personnel needed in these specific job categories.

To accomplish this task, we first estimated the level of design and construction resources related to revamped and new desulfurization equipment. We next projected the number of revamped and new desulfurization units which would be needed under the proposed NRLM fuel program, as well as under a couple of alternative programs also considered. Then, we developed a schedule for how desulfurization projects due to be completed at the same time might be spread out during the year. We next developed a time schedule for when the various resources would be needed throughout each project. Finally, we project the level of design and construction resources needed in each month and year from 2003 and 2014 and compare this to the number of people employed in each job category.

5.7.1 Design and Construction Resources Related to Desulfurization Equipment

The number of job-hours necessary to design and build individual pieces of equipment and the number of pieces of equipment per project were taken from an NPRA technical paper by Moncrief and Ragsdale.[36] Their study was performed to support a recent National Petroleum Council study of gasoline and diesel fuel desulfurization, as well as other potential fuel quality changes.[37] These estimated job hours are summarized in Table 5.7-1.

Table 5.7-1
Design and Construction Factors for Desulfurization Equipment

	Gasoline[a]	Highway and Nonroad Diesel Treaters	Highway and Nonroad Diesel Treaters
	New Hydrotreater	New Hydrotreater	Revamp Existing Hydrotreater
Number of Pieces of Equipment per Refinery	60	60	30
Job hours per piece of equipment[a]			
Front End Design	300	300	150
Detailed Design	1200	1200	600
Direct and indirect construction	9150	9150	4575

[a] Revamped equipment estimated to require half as many hours per piece of equipment. All gasoline treaters for Tier 2 compliance are assumed to be new.

5.7.2 Number and Timing of Revamped and New Desulfurization Units

In the Final Regulatory Impact Analysis for the 2007 highway diesel program, we estimated the number of new and revamped desulfurization units projected for both the Tier 2 and highway diesel fuel programs.[38] We updated the projections for the 2007 highway diesel program per the analysis presented in Section 7.2.2.1. These projections are shown in Table 5.7-2 below.

Table 5.7-2
Number of Gasoline and Highway Diesel Desulfurization Units Becoming Operational[a39]

Fuel Type and Stage	Before 2004	2004	2005	2006	2007	2008	2009	2010
New gasoline desulfurization units	10	37	6	26	5	3	4	6
Highway Diesel Desulfurization Units (80% revamps, 20% new)				74				40

[a] Units become operational on January 1st for gasoline desulfurization and June 1st for highway diesel desulfurization l units.

The next step was to estimate the types of equipment modifications necessary to meet the proposed NRLM fuel requirements. This was a complex task, due to the close integration of the highway and NRLM fuel programs and the fact that refiners' relative production of highway and high sulfur distillate fuel varies dramatically. Therefore, we broke refiners of high sulfur distillate into three categories and assessed their need for new or revamped desulfurization equipment separately. The categories as discussed in Section 7.2.1 are: highway refiners (95% or more of their no. 2 distillate production meets highway diesel fuel specifications), high sulfur refiners (5% or less of their no. 2 distillate production meets highway diesel fuel specifications), mix refiners (producers of high sulfur distillate fuel not falling into one of the other categories).

Table 5.7-3 presents the results of our analysis of the 62 refineries which are projected to produce either 500 or 15 ppm NRLM diesel fuel under the proposed program. The methodology used to determine that these 62 refineries would produce NRLM diesel fuel is described in Section 7.2.

Table 5.7-3
Types of Equipment Modifications Needed Under the Proposed NRLM Fuel Program

Fuel Type	Year and Fuel Control	Highway Refiners	Mix 2006 Refiners[a]			Mix 2010 Refiners[a]			High Sulfur Refiners	
		Units	New Units	Revamp Units	None	New Units	Revamp Units	None	Units	Revamp
15 ppm Highway Diesel Hydrotreater Modifications	2006	8	7 (4)	12					0	
	2010	2				11 (9)	8		0	
	Total	10	19			19			14	
High Sulfur Diesel Hydrotreater Modifications	2007 500 ppm fuel (total of 42)	7	12 (1)	0	3	12 (4)	0	0	8	0
	2010 500 ppm fuel (total of 20)	3	4 (3)	0	0	0	7 (5)	0	6	0
	2010 15 ppm fuel (total of 25)	5	2	6 (1)	0	0	0	8 (2)	0	4
	2014 15 ppm fuel (total of 12)	3	0	5 (3)	0	0	4 (3)	0	0	0

[a] Numbers in parentheses are a subset for each category and represent mix refineries that currently have no highway diesel fuel hydrotreater.

As shown in the Table 5.7-3, we project that 10 highway refineries, 38 mix refineries and 14 high sulfur refineries are projected to produce NRLM diesel fuel in 2007 and beyond. Refineries in the first two categories also produce highway diesel fuel. We further sub-divide refineries in these two categories according to whether they are projected to produce 15 ppm highway diesel fuel in 2006 or 2010, because the timing of their modifications to their highway diesel fuel hydrotreater can affect what modifications are necessary to produce 500 ppm or 15 ppm NRLM diesel fuel. As shown, of the 10 highway refineries, we project that 8 will revamp or replace their current hydrotreater in 2006, while the other two will do so in 2010. Of the 38 mix refineries, we project that half will revamp or replace their current hydrotreater in 2006, while the other half will do so in 2010. No current high sulfur refineries are projected to produce 15 ppm highway diesel fuel in either 2006 or 2010. It should be noted that the 48 highway and mix refineries shown in Table 5.7-3 are not all the refineries producing highway diesel fuel today or in 2006 and beyond. The 48 refineries are those which are projected to produce some highway diesel fuel in 2006 and beyond, as well as NRLM fuel in 2007 and beyond.

Regarding the highway refineries, our cost analysis projects that 7 would produce 500 ppm NRLM fuel in 2007. Five of these refineries would further desulfurize their 500 ppm NRLM diesel fuel to 15 ppm in 2010, while three new highway refineries would produce 500 ppm NRLM diesel fuel for the first time in 2010. Finally, in 2014, an additional three refineries would further desulfurize their 500 ppm NRLM diesel fuel to 15 ppm in 2014, leaving 2 highway refineries producing 500 ppm NRLM diesel fuel in the long term.

As mentioned above, the highway refineries produce relatively small quantities of high sulfur distillate today (i.e., less than 5% of total no. 2 distillate production). Thus, we project that these refineries could incorporate their high sulfur distillate into the design and construction of their highway hydrotreaters with no additional engineering or construction requirements. Section 7.2.2 describes the type of hydrotreater modifications which are projected for highway refineries to enable the production of low sulfur NRLM diesel fuels.

Moving to the mix refineries, their treatment depends on when they are projected to produce 15 ppm highway diesel fuel and whether or not they would do so by revamping their current hydrotreater or construct the new hydrotreater. Of the 19 mix refineries which are projected to produce 15 ppm highway diesel fuel in 2006 (“2006 mix refineries”), we project that 7 would construct a new hydrotreater. We project that 4 of these 7 refineries would need a new hydrotreater because available data indicate that they do not currently have a no. 2 distillate hydrotreater. We assumed that 20% of the remaining 15 refineries (3 refineries) would need a new hydrotreater. This is consistent with the analysis and assumptions for the 2007 highway rule, where we estimated that 20% of all refineries producing highway diesel fuel would need a new hydrotreater. Discussions with industry continue to confirm the reasonableness of this assumption. (The other 80% are projected to be able to revamp their current hydrotreater to produce 15 ppm diesel fuel.) The same procedure was applied to the 19 mix refineries projected to produce 15 ppm highway diesel fuel initially in 2010 (“2010 mix refineries”). The only difference was that 9 of these refineries apparently do not currently have a no. 2 distillate hydrotreater, therefore necessitating that a new one be built.

In 2007, we project that 15 2006 mix refineries would begin producing 500 ppm NRLM diesel fuel. Twelve of these are projected to need to construct a new hydrotreater to do so, while three do not. These three refineries are those which built new hydrotreaters in 2006 to produce 15 ppm highway diesel fuel and which also currently have a highway diesel fuel hydrotreater. These three refineries could use their current highway diesel fuel hydrotreater to produce 500 ppm NRLM diesel fuel. Four additional 2006 mix refineries would begin producing 500 ppm NRLM diesel fuel in 2010, with all needing to construct new hydrotreaters to do so.

We project that 13 of the 19 2006 mix refineries would produce 15 ppm nonroad diesel fuel, beginning either in 2010 or 2014. All but two of these units would be revamps of units built in 2007. The two new 15 ppm units would be at refineries projected to produce 500 ppm NRLM diesel fuel in 2007 with the current highway diesel fuel hydrotreater.

In 2007, we project that 12 2010 mix refineries would begin producing 500 ppm NRLM diesel fuel. All of these refineries are projected to need to construct a new hydrotreater to do so, because they will need their existing hydrotreater to continue producing 500 ppm highway diesel fuel through 2009. Seven additional 2010 mix refineries would begin producing 500 ppm NRLM diesel fuel in 2010. All seven of these refineries are projected to incorporate the desulfurization of NRLM diesel fuel into their plans for producing 15 ppm highway diesel fuel in 2010. Due to the significant volume of NRLM fuel involved, we project that the resources needed to add the desulfurization of NRLM fuel to their plans would constitute a revamp of a desulfurization unit.

We project that 12 of the 19 2010 mix refineries would produce 15 ppm nonroad diesel fuel, beginning either in 2010 or 2014. The 10 refineries beginning 15 ppm nonroad fuel production in 2010 are projected to not require significant amounts of additional design and construction resources, as these units were designed in 2007 to be easily revamped in 2010 to produce 15 ppm fuel. The 4 refineries beginning 15 ppm nonroad fuel production in 2014 are projected to require a modest amount of additional design and construction resources (revamp level), as these refineries built new desulfurization capacity in 2010 to produce 500 ppm NRLM fuel at the same time that they began production of 15 ppm highway diesel fuel. Therefore, we projected that they would likely require some additional engineering and construction resources to produce 15 ppm nonroad fuel in 2014.

Moving to the high sulfur refineries, we project 8 such refineries would begin producing 500 ppm NRLM diesel fuel in 2007 and 6 more refineries in 2010. All of these refineries are projected to need to construct a new hydrotreater to produce 500 ppm NRLM fuel, because their existing hydrotreating capacity is likely only capable of producing 2000-5000 ppm sulfur levels. In 2010, we project that 4 of these refineries producing 500 ppm NRLM diesel fuel in 2007 would revamp their units to produce 15 ppm nonroad diesel fuel.

We repeated this analysis for two of the alternative NRLM fuel programs considered in developing this proposed rule: 1) the proposed program plus extension of the 15 ppm cap to locomotive and marine diesel fuel in 2010 (two step 15 ppm NRLM) and 2) a one step program consisting of the final standards as the proposal, but with all the standards occurring in 2008 (one step in 2008). The breakdown of desulfurization equipment modifications required under the two step 15 ppm NRLM program are summarized in Table 5.7-4. There are no differences between this program and the proposal with respect to the production of 500 ppm fuel in 2007 in 2010. However, due to the further control of locomotive and marine diesel fuel to 15 ppm in 2010, additional new and revamped units would be needed in 2010.

We again repeated this analysis for the one step NRLM fuel program in 2008. The results are shown in Table 5.7-5. The key difference here is that most new and revamped units occur in 2008. Also, we project more revamped units and fewer new units for 2010 mix refineries as we project that these refineries would combine their plans to produce 15 ppm highway and nonroad diesel fuel.

Table 5.7-6 summarizes the results of Tables 5.7-3 through 5.7-5.

Table 5.7-4
Types of Equipment Modifications Needed Under the Two Step Alternative Program with 15 ppm NRLM Diesel Fuel in 2010

Fuel Type	Year and Fuel Control	Highway Refiners	Mix 2006 Refiners[a]			Mix 2010 Refiners[a]			High Sulfur Refiners	
		Units	New Units	Revamp Units	None	New Units	Revamp Units	None	Units	Revamp
15 ppm Highway Diesel Hydrotreater Modifications	2006	8	7 (4)	12					0	
	2010	2				11 (9)	8		0	
	Total	10	19			19			14	
High Sulfur Diesel Hydrotreater Modifications	2007 500 ppm fuel (total of 42)	7	12 (1)	0	3	12 (4)	0	0	8	0
	2010 500 ppm fuel (total of 20)	3	4 (3)	0	0	0	7 (5)	0	6	0
	2010 15 ppm fuel (total of 43)	7	2	13 (1)	0	0	0	15 (2)	0	6
	2014 15 ppm fuel (total of 12)	3	0	5 (3)	0	0	4 (3)	0	0	0

[a] Numbers in parentheses are a subset for each category and represent mix refineries that currently have no highway diesel fuel hydrotreater.

Table 5.7-5
Types of Equipment Modifications Needed Under the One Step Alternative Program with 15 ppm Nonroad and 500 pmm L&M Fuel in 2010

Fuel Type	Year and Fuel Control	Highway Refiners	Mix 2006 Refiners[a]			Mix 2010 Refiners[a]			High Sulfur Refiners	
		Units	New Units	Revamp Units	None	New Units	Revamp Units	None	Units	Revamp
15 ppm Highway Diesel Hydrotreater Modifications	2006	8	7 (4)	12					0	
	2010	3				11 (9)	10		0	
	Total	11	19			21			13	
High Sulfur Diesel Hydrotreater Modifications	2008 500 ppm fuel (total of 13)	0	4	0	1	0	5 (2)	0	3	0
	2008 15 ppm fuel (total of 30)	7	10 (1)	0	0	0	7 (2)	0	6	0
	2012 500 ppm fuel (total of 12)	2	1	0	0	0	4 (2)	0	5	0
	2012 15 ppm fuel (total of 7)	1	(3)	0	0	0	3 (3)	0	0	0

[a] Numbers in parentheses are a subset for each category and represent mix refineries that currently have no highway diesel fuel hydrotreater.

Table 5.7-6
Number and Timing of NRLM Desulfurization Units

Program	Type of Treater	2007	2008	2009	2010	2011	2012	2013	2014
Proposed Two Step Program	No Treaters Modification	10			16				3
	Revamp Treaters	0			17				9
	New Treaters	32			12				0
	Total Units	42			45				12
Proposed Two Step Program with 15 ppm Locomotive and Marine Fuel in 2010	No Treaters Modification	10			25				3
	Revamp Treaters	0			26				16
	New Treaters	32			11				0
	Total Units	42			62				19
One Step NRLM Program in 2008	No Treaters Modification		7				3		
	Revamp Treaters		12				7		
	New Treaters		24				9		
	Total Units		43				19		

5.7.3 Timing of Desulfurization Projects Starting up in the Same Year

A worst case assumption would be that all of the units scheduled to start up on January 1 for gasoline and June 1 for diesel would begin and complete their design and construction at the exact same time. However, this is not reasonable for a couple of reasons. Our early credit programs for gasoline, highway and nonroad diesel production will entice some refiners to make treater modifications ahead of our program startup dates thus shifting E&C workload ahead for these refiners. Also, an industry-wide analysis such as this one assumes that all projects take the same amount of effort and time. This means that each refinery is using every specific type of resource at exactly the same time as other refineries with the same start-up date. However, refineries' projects will differ in complexity and scope. Even if they all desired to complete their project on the same date, their projects would begin over a range of months. Thus, two projects scheduled to start up at exactly the same time are not likely to proceed through each step of the design and construction process at the same time. Second, the design and construction industries will likely provide refiners with economic incentives to avoid temporary peaks in the demand for personnel. Thus, with respect to units starting up in a given year, we assumed that the design and construction of these units would be spread out throughout the year, with 25 percent of the units starting up per quarter. Given this assumption, we developed the breakdowns of personnel requirements by month for a given project shown in Table 5.7-7.

5.7.4 Timing of Design and Construction Resources Within a Project

The next step in this analysis was to estimate how the engineering and construction resources are spread out during a project. The results of this analysis are summarized in Table 5.7-7.

Table 5.7-7
Distribution of Personnel Requirements Throughout the Project

	Front-End Design	***Detailed Engineering***	***Construction***
Duration per project	6 months	11 months	14 months
Duration for projects starting up in a given calendar year	15 months	20 months	23 months
Fraction of total hours expended per month from start of that portion of the project			
1	0.050	0.020	0.030
2	0.050	0.030	0.030
3	0.050	0.040	0.030
4	0.078	0.040	0.040
5	0.078	0.040	0.040
6	0.078	0.050	0.040
7	0.078	0.050	0.040
8	0.078	0.060	0.050
9	0.078	0.065	0.050
10	0.078	0.075	0.055
11	0.078	0.075	0.055
12	0.078	0.075	0.060
13	0.050	0.060	0.060
14	0.050	0.060	0.055
15	0.050	0.050	0.055
16		0.050	0.050
17		0.040	0.050
18		0.040	0.040
19		0.030	0.040
20		0.020	0.040
21			0.030
22			0.030
23			0.030

The figures shown in Table 5.7-7 were taken from a similar analysis performed in support of the 2007 highway diesel fuel program. The fraction of total hours expended each month estimated in Table 5.7-7 was derived based on the following. Per Moncrief and Ragsdale, front end design typically takes six months to complete.[40] If 25 percent of the refineries scheduled to start of in a given year start their projects every quarter, each subsequent group of the refineries starts when the previous group is halfway through their front end design. Overall, front end design for the four groups covers a period of 15 months, or 6 months for the first group plus 3 months for each of the three subsequent groups. In spreading this work out over the 15 months, we assumed that the total engineering effort would be roughly equal over the middle 9 months. The effort during the first and last 3 month period would be roughly two-thirds of that during the peak middle months. The same process was applied to the other two job categories. Finally, we assumed that personnel were able to actively work 1877 hours per year, or at 90 percent of capacity assuming a 40 hour work week. The reader is referred to the Final RIA for the 2007 highway diesel rule for a more detailed description of the methodology used.

5.7.5 Projected Levels of Design and Construction Resources

Applying the above factors, we projected the maximum number of personnel needed in any given month for each type of job for the desulfurization projects related to the Tier 2 gasoline, highway diesel fuel and NRLM diesel fuel programs combined . The results are shown in Table 5.7-8. In addition to total personnel required, the percentage of the U.S. workforce currently employed in these areas is also shown. These percentages were based on estimates of recent employment levels for the three job categories: 1920 front end design personnel, 9585 detailed engineering personnel and roughly 160,000 construction workers (taken from Moncrief and Ragsdale).

Table 5.7-8
Maximum Monthly Demand for Personnel

	Front-End Design	***Detailed Engineering***	***Construction***
Tier 2 Gasoline Sulfur Program Plus Highway Diesel Fuel Program			
Number of Workers	630 (Apr 03)	2,223 (Apr 04)	14,614 (Nov 04)
Current Workforce [a]	33%	23%	9%
With Proposed Two Step NRLM Program			
Number of Workers	630 (Apr 03)	2,223 (Apr 04)	17,176 (Dec 04)
Current Workforce [a]	33%	23%	11%
With Proposed Two Step NRLM Program with 15 ppm NRLM in 2010			
Number of Workers	630 (Apr 03)	2,223 (Apr 04)	17,076 (Dec 04)
Current Workforce [a]	33%	23%	11%
With One Step NRLM Program in 2008			
Number of Workers	630 (Apr 03)	2,223 (Apr 04)	14,614 (Dec 04)
Current Workforce [a]	33%	23%	9%

[a] Based on recent employment in the U.S. Gulf Coast, assuming that half of all projects occur in the Gulf Coast. The year and month of maximum personnel demand is shown in parenthesis.

As can be seen from Table 5.7-8, the proposed NRLM diesel fuel program does not impact the maximum monthly personnel requirements for either front end design or detailed engineering design. Maximum use of construction personnel is increased slightly, by 2% in November of 2004. This appears to be a minor impact. The primary reason for the lack of impact is that the 2007 implementation date for the 500 ppm NRLM standard is later than the primary 2004-2006 phase-in period for the Tier 2 gasoline program and the 2006 implementation date for the 15 ppm highway diesel fuel standard.

The alternative two step NRLM program with a 15 ppm cap on locomotive and marine diesel fuel would have the same impact, since the difference between this alternative and the proposal occurs in 2010, after the peak impacts occurs. The alternative one step NRLM fuel program in 2008 avoids any impact on the peak resource need due to its starting one year later.

Tables 5.7-9, 5.7-10 and 5.7-11 present a summary of the average personnel demand for the three job categories in each year.

Table 5.7-9.
Annual Front End Engineering Personnel Demand

Calendar Year	*Gasoline + Highway Diesel Baseline*	*Plus Two Step Nonroad to 15 ppm in 2010*	*Plus Two Step to 15 ppm in 2010*	*Plus One Step to 15 ppm in 2008*
2003	534	549	549	534
2004	83	344	344	100
2005	32	64	64	325
2006	57	67	67	9
2007	231	398	444	231
2008	23	42	48	29
2009	0	0	0	102
2010	0	2	4	18
2011	0	37	65	0
2012	0	4	8	0
2013	0	0	0	0
2014	0	0	0	0

Table 5.7-10
Annual Detailed Engineering Personnel Demand

Calendar Year	*Gasoline + Highway Diesel Baseline*	*Plus Two Step Nonroad to 15 ppm in 2010*	*Plus Two Step to 15 ppm in 2010*	*Plus One Step to 15 ppm in 2008*
2003	1166	1166	1166	1166
2004	1656	1988	1988	1656
2005	372	1207	1207	682
2006	345	407	407	1128
2007	593	806	842	651
2008	757	1292	1383	757
2009	46	84	92	175
2010	0	0	0	326
2011	0	46	83	24
2012	0	117	209	0
2013	0	9	15	0
2014	0	0	0	0

Table 5.7-11
Construction Worker Personnel Demand

Calendar Year	*Gasoline + Highway Diesel Baseline*	*Plus Two Step Nonroad to 15 ppm in 2010*	*Plus Two Step to 15 ppm in 2010*	*Plus One Step to 15 ppm in 2008*
2003	4,914	4,914	4,914	4,914
2004	12,462	12,743	12,742	12,462
2005	7,653	12,800	12,800	7,916
2006	249	4,179	4,179	5,074
2007	579	759	790	4,264
2008	4,948	8,246	8,810	4,948
2009	3,246	5,764	6,194	3,356
2010	0	0	0	2,010
2011	0	40	70	1,535
2012	0	724	1,287	0
2013	0	553	983	0
2014	0	0	0	0

The impact of the nonroad programs on the maximum monthly demand for front end design is not increased from the 2000 highway rule determinations. Thus, 33 percent of available front end personnel U.S. resources are required for the nonroad programs which is not different than the maximum predicted impact for the highway diesel rule. The annual front end demand for personnel in Table 5.7-9 reveals that the front end resource demands are spaced over many years with an initial peak in years 2003-04 and a second sub peak in 2006-07. The level of front end resource demand drops off dramatically after years 2003 and 2004. Detailed engineering annual demands for nonroad has a maximum peak in years 2003-05 and a second sub peak in years 2006-08. Neither of the peaks represent a significant percentage of available detailed resources and furthermore are not higher than demands determined for the highway diesel program. The nonroad programs contribute to the second peak in front end engineering and detailed engineering in demands in 2006-07, but we believe the yearly time spread in peak resource demand will provide an ample period for E&C industry to respond to nonroad implementation. The maximum monthly impact on construction services is not significant at eleven percent of available industry which is not considerably increased over highway diesel requirements, see Table 5.7-11. Thus, we believe the construction industry should be able to provide services for the nonroad programs.

Thus, we believe that the E&C industry is capable of supplying the refining industry with the equipment necessary to comply with our proposed nonroad diesel fuel programs. We believe that this is facilitated by the synergies obtained with highway diesel rule implementation and the later phase in dates for nonroad compliance.

5.8 Supply of Nonroad, Locomotive, and Marine Diesel Fuel (NRLM)

EPA has developed the proposed fuel program to minimize its impact on the supply of distillate fuel. For example: we have proposed to transition the fuel sulfur level down to 15 ppm in two steps, providing an estimated 6 years of leadtime for the final step; up to 10 years for small refiners. We are proposing to provide flexibility to refiners through the availability of banking and trading provisions and we are proposing hardship provisions for qualifying refiners. In order to evaluate the effect of this proposal on supply, EPA evaluated four possible cases: 1) whether today's proposed standards could cause refiners to remove certain blendstocks from the fuel pool, 2) whether the proposed standards could require chemical processing which loses fuel in the process, 3) whether the cost of meeting the proposed standards could lead some refiners to leave that market, and 4) whether the cost of meeting the proposed standards could lead some refiners to stop operations altogether (i.e., shut down). In all cases, as discussed below, we have concluded that the answer is no. Therefore, consistent with our findings made during the 2007 highway diesel rule, we do not expect this proposed rule to cause any supply shortages of nonroad, locomotive and marine diesel fuel.

Blendstock Shift: As mentioned above, we first evaluated whether certain blendstocks or portions of blendstocks may need to be removed from the NRLM diesel fuel pool. Technology exists to desulfurize any commercial diesel fuel to less than 10 ppm sulfur. Technologies, such as hydro-dearomatization, have been used on a commercial scale. More direct, desulfurization technologies are just being demonstrated as refiners in both the U.S. and Europe are producing selected batches of number 2 diesel fuel at 15 ppm sulfur or less. Pilot plant studies have demonstrated that diesel fuels consisting of a wide range of feedstocks and containing high levels of sulfur can be desulfurized to less than 15 ppm. Such studies and experience have reliably demonstrated that at pressures within the range of many current conventional hydrotreaters, the single most important variable that limits desulfurization to very low sulfur levels is the length of time the fuel is in contact with hydrogen and the catalyst. This "residence time" is primarily a function of reactor volume. Therefore, we believe there is no technical reason to remove certain feedstocks from the diesel fuel pool. It may cost more for refiners to process certain blendstocks, such as light cycle oil, than others. Consequently, there may be economic incentives for refiners to move these blendstocks out of the diesel fuel market to reduce compliance costs. However, that is an economic issue, not a technical issue and will be addressed below. Thus, this rulemaking should not result in any long term reduction in the volume of products derived from crude oil available for blending into diesel fuel or heating oil.

As mentioned above, certain feedstocks are more expensive to desulfurize than others. The primary challenge of desulfurizing distillate to sulfur levels meeting the 15 ppm cap is the presence of sterically hindered compounds, particularly those with two methyl or ethyl groups blocking the sulfur atom[J]. These compounds are aromatic in nature, and are found in greatest concentration in light cycle oil (LCO), which itself is highly aromatic. These compounds can be desulfurized readily if saturated. However, due to the much higher hydrogen cost of doing so, it is better economically if this can be avoided. Because these compounds are large in size and high in molecular weight due to their chemical structure, they distill near the high end of the diesel range of distillation temperatures. Thus, it is technically possible to segregate these compounds from the rest of the cracked stocks via distillation and avoid the need to desulfurize them. However, this would likely require the construction of a distillation column and significant operating costs in the form of heat input. Another option would be to use the existing FCC fractionator to shift these heavy molecules out of the LCO pool. They would be shifted to slurry oil, which eventually becomes part of residual fuel. Once there, it would be very difficult to recover them for blending into heating oil. Residual fuel is priced well below diesel fuel. The residual fuel oil market is also not growing. Thus, shifting heavy LCO to residual fuel would involve a significant long term reduction in revenue (and profits). Thus, we do not believe that many refiners would attempt to reduce the cost of desulfurizing diesel fuel in this way.

It is more feasible to shift some or all of the LCO stream to the heating oil pool. It is unlikely to be shifted to locomotive and marine (LM) diesel fuel due to their 40 minimum cetane specification and the very low cetane level of LCO. Straight run distillate could be shifted from heating oil to diesel fuel to compensate for the volume. Thus, little if any volume loss of NRLM diesel fuel should result. However, even this approach would require the refiner to maintain separate inventories of NRLM diesel fuel and heating oil, which may require additional tankage. Of course, the refiner would need to have access to a significant heating oil market after 2007.

In our cost projections, we projected that individual refineries would produce either 15 ppm, 500 ppm or high sulfur distillate to avoid additional tankage and maximize economies of scale for the desulfurization equipment. Thus, we did not assume that refiners could reduce costs by shifting feedstocks around, such as sending LCO to heating oil and straight run from heating oil to NRLM diesel fuel. Despite this, the costs appear to be reasonable. Thus, some refiners with adequate tankage and access to the heating oil market may be able to reduce costs with such an exchange of feedstocks. However, we did not factor these savings into our cost projections. Nor should such exchanges reduce the supply of NRLM diesel fuel.

Processing Losses: We evaluated whether the proposed standards could require chemical processing which results in fuel losses. Conventional desulfurization processes do not reduce the energy content of feedstocks, although the feedstock composition may be slightly altered. A conventional hydrotreater which is used to produce 15 ppm sulfur diesel converts about 98 percent of its feedstock to finished diesel fuel. About 1.5 percent of the remaining two-percent leaves the unit as naphtha or light-crackate (i.e., gasoline feedstock), while the last 0.5 percent is split about evenly between liquified petroleum gas (LPG) and refinery fuel gas. Both naphtha and LPG are valuable liquids which are used to produce other finished products including

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[J] Meeting a 500 ppm cap standard can be met without desulfurizing much or any of the sterically hindered compounds.

gasoline. Refiners can easily adjust the relative amounts of gasoline and diesel fuel produced by a unit, especially at the process level under discussion. This additional naphtha can displace other gasoline or kerosene blendstocks, which can then be shifted to the diesel fuel pool. LPG, on the other hand, is used primarily for space-heating, but depending on where it's produced and how it's cut, can be used as a feedstock in the petrochemical industry. Because LPG can be used for space heating, it would likely displace some volume of heating oil, which in turn could be shifted to the diesel pool. Currently, heating oil or high sulfur fuel, has the same basic composition as highway diesel, other than its sulfur content, and can be used to fuel nonroad, locomotive, and commercial marine equipment. Thus, the desulfurization process usually has little or no direct impact on a refinery's net fuel production. The volume-shift from diesel fuel to fuel gas is very small (0.25 percent) and the gas can be used to reduce consumption of natural gas within the refinery. This discussion applies to the full effect of the proposed standards (i.e., the reduction in sulfur content from 3400 ppm to 500 ppm and from 500 ppm to 15 ppm). For the first step of the proposed fuel program and that portion of the diesel fuel pool which would remain at the 500 ppm level indefinitely, the impacts would only be about 40 percent of those described above.

The conversion rate of a given feedstock to light products is reportedly much lower for the emerging or advanced technologies than for conventional hydrotreaters. For the purposes of this rulemaking, the newer or advanced technologies are only projected to be used as a second step to reduce the fuel to 15 ppm sulfur after it has been reduced from 3400 ppm to 500 ppm using conventional hydrotreating technology. We project that the Linde process might reduce the conversion to light products for the second step by 55 percent, while the Phillips SZorb® process reportedly would not convert any diesel to light products.

Exit the NRLM Diesel Fuel Market: We evaluated whether the compliance costs associated with this rulemaking could cause some refiners to consider reducing their production of NRLM or to leave those markets altogether. As mentioned above, diesel fuel and heating oil are chemically and physically similar, except for sulfur level. Thus, beginning in mid-2007, a refiner could shift his high sulfur distillate from NRLM fuel to the heating oil market and avoid the need to invest in new desulfurization equipment. Likewise, beginning in mid-2010, a refiner could either focus entirely on the 500 ppm LM markets or shift part or all of its supply to heating oil. The result would be a potential oversupply of heating oil beginning in 2007 and LM fuel and heating oil beginning in 2010. We expect such an oversupply of these fuels would result in a substantial drop in their market price and would consequently increase the cost for a given refiner to exit the NRLM diesel fuel markets. Furthermore, refiners could be forced to find new export markets for their excess high sulfur fuel. Overseas market prices are often no higher and are occasionally lower than those in the U.S. We believe that these low market differentials combined with the additional transportation costs would encourage most refiners to comply with the NRLM program to remain in the domestic low sulfur fuel markets.

We addressed this same issue during the development of the highway diesel rule (66 FR 5002). We contracted with Southwest Research Institute (SwRI) and with Muse, Stancil & Company, an engineering firm involved primarily in economic studies and evaluations concerning the refining industry to help us assess the potential for refiners to sell their highway diesel fuel (< 500 ppm) or the blendstocks used to produce it into alternative markets. At that time, Muse, Stancil & Company found that most refiners had few domestic alternatives for accommodating highway diesel fuel or its blendstocks. PADD I imports significant quantities of high sulfur fuel for use as nonroad diesel fuel and heating oil. Muse, Stancil & Company concluded that PADD I refineries could produce less highway fuel and more high sulfur fuel and still avoid over supplying the market by reducing imports. However, refineries in other PADDs which import little, if any, high sulfur fuel would be forced to find other, less valuable markets, including new markets for export, if they exited the highway diesel fuel market. We concluded that, at current production levels, refiners faced greater economic losses trying to avoid meeting the 15 ppm cap than by trying to comply with it, even if the market did not allow them to recover their capital investment.

There are six reasons why we believe a similar conclusion can be drawn from an analysis of today's proposed rule:

1. Approximately one-half of what is currently the U.S. high-sulfur diesel fuel market will have become part of the 500 ppm and 15 ppm markets by the time the 2007 highway diesel rule and the proposed sulfur caps on NRLM fuel have been implemented. Within that same timeframe, we expect few, if any, of the common carrier pipelines, except perhaps those serving the Northeast, will carry high sulfur heating oil. Therefore, the sale of high sulfur distillate may be limited to markets that a refiner can serve by truck.

2. The technology to desulfurize fuel, including refractory feedstocks, to less than 500 ppm sulfur has been used commercially for over a decade. The technology to reduce fuel to less than 15 ppm sulfur will have been commercially demonstrated in mid-2006, a full four years prior to the implementation of the 15 ppm sulfur standard for nonroad diesel fuel.

3. The volume of fuel affected by the 15 ppm nonroad diesel fuel standard in 2010 would be only one-seventh of that affected by the 2007 highway diesel program. This dramatically reduces the required capital investment.

4. Both Europe and Japan are implementing rules to reduce sulfur levels in highway and nonroad diesel fuel to the 10-15 ppm range, which will effectively eliminate these regions as alternative export markets for high sulfur fuel.

5. Refineries outside of the U.S. and Europe are operating at a lower percentage of their capacity than U.S. refineries.[K] Capacity utilization rates at U.S. refineries are well over 90 percent. Historically, if refinery utilization rates approached their maxima, it was

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[K] Europe currently imports diesel fuel and is expected to continue to do so. However, European sulfur caps will be equivalent to those in the U.S. Therefore, exporting distillate fuel to Europe is not an option for U.S. refiners to avoid complying with stringent sulfur caps here. Likewise, imports from European refiners are not likely.

usually a strong indication that demand for finished products was high. In this environment, product prices usually rose and held until the demand pressure was reduced or eliminated. Foreign refinery utilization rates as well as wholesale prices tend to be well below domestic rates, again, a reflection of lower demand relative to the potential output of finished products. The preceding condition can have at least two effects on the marketing decisions domestic refiners may face. First, if foreign margins are low and U.S. market prices high, a foreign refiner could, and most likely would, sell his products into the U.S. market, thereby reducing the upward pressure on prices and likely reducing domestic refinery margins. And, second, it is highly unlikely that a domestic refiner would decide to further reduce his margins by adding the cost to ship his product into a foreign market with a less stringent sulfur standard where wholesale prices are already lower than in the U.S. Consequently, we do not believe U.S. refiners will have a reasonable opportunity to export their high sulfur fuel.

6. One measure of the overall fiscal well-being of a refining operation is its margin. Refinery profit margins[L] during the 1990s were not very encouraging until about 1997. In fact, in 1994, the net margin was less than $0.50 per refined barrel. By 1997 it had nearly tripled and by 2000 had increased to nearly five times the 1994 average. Margins leveled out again during 2001 and decreased somewhat during 2002, but recovered during the last few months of 2002 and in early 2003. Current industry projections into the future indicate the expectation for continued high profit margins.

Once refiners have made their investments to meet the proposed NRLM diesel fuel standards, or have decided to produce high sulfur heating oil, we expect that the various distillate markets would operate very similar to today's markets. When fully implemented in 2014, there will be three distillate fuels in the market, 15 ppm highway and nonroad diesel fuel, 500 ppm locomotive and marine diesel fuel and high sulfur heating oil. The market for 500 ppm locomotive and marine diesel fuel is much smaller than the other two, particularly considering that it is nationwide and the heating oil market is geographically concentrated. Therefore, the vast majority of refiners are expected to focus on producing either 15 ppm or high sulfur distillate, which is similar to today, where there are two fuels, 500 ppm and high sulfur distillate. In this case, refiners with the capability of producing 15 ppm diesel fuel have the most flexibility, since they can sell their fuel to any of the three markets. Refiners with only 500 ppm desulfurization capability can supply two markets. Those refiners only capable of producing high sulfur distillate would not be able to participate either the 15 or 500 ppm markets. However, this is not different from today. Generally, we do not expect one market to provide vastly different profit margins than the others, as high profit margins in one market will attract refiners from another via investment in desulfurization equipment.

[L] The terms "margin" or the plural "margins" are often used in the petroleum industry in reference to several different variables including "spread" or "spreads," "net margin" or "cash margin," "gross margin," and "profit margin." The numbers these terms represent are all basically a measure of a revenue minus the cost to produce that revenue, expressed on a per barrel basis of either crude oil or finished product(s).

Refinery Closure: There are a number of reasons why we do not believe that refineries would completely close down under this proposed rule. One reason is that we have included a provisions in the proposed regulations for adjustments to the sulfur caps for small refiners, as well as any refiner facing unusual financial hardship. Another reason is that nonroad, locomotive and marine diesel fuel is usually the third or fourth most important product produced by the refinery from a financial perspective. A total shutdown would mean losing all the revenue and profit from these other products. Gasoline is usually the most important product, followed by highway diesel fuel and jet fuel. A few refineries do not produce either gasoline or highway diesel fuel, so jet fuel and high sulfur diesel fuel and heating oil are their most important products. The few refiners in this category likely face the biggest financial challenge in meeting today's proposed requirements. However, those refiners would also presumably be in the best position to apply for special hardship provisions, presuming that they do not have readily available source of investment capital. The additional time afforded by these provisions should allow the refiner to generate sufficient cash flow to invest in the required desulfurization equipment. Investment here could also provide them the opportunity to expand into more profitable (e.g., highway diesel) markets.

A quantitative evaluation of whether the cost of the proposed fuel program could cause some refineries to cease operations completely would be very difficult, if not impossible to perform. A major factor in any decision to shut down is the refiner's current financial situation. It is very difficult to assess an individual refinery's current financial situation. This includes a refiner's debt, as well as its profitability in producing fuels other than those affected by a particular regulation. It can also include the profitability of other operations and businesses owned by the refiner.

Such an intensive analysis can be done to some degree in the context of an application for special hardship provisions, as discussed above. However, in this case, EPA can request detailed financial documents not normally available. Prior to such application, as is the case now, this financial information is usually confidential. Even when it is published, the data usually apply to more than just the operation of a single refinery.

Another factor is the need for capital investments other than for this proposed rule. EPA can roughly project the capital needed to meet other new fuel quality specifications, such as the Tier 2 or highway diesel sulfur standards. However, we cannot predict investments to meet local environmental and safety regulations, nor other investments needed to compete economically with other refiners.

Finally, any decision to close in the future must be based on some assumption of future fuel prices. Fuel prices are very difficult to project in absolute terms. The response of prices to changes in fuel quality specifications, such as sulfur content, as is discussed in the next section, are also very difficult to predict. Thus, even if we had complete knowledge of a refiner's financial status and its need for future investments, the decision to stay in business or close would still depend on future earnings, which are highly dependent on prices.

Some studies in this area point to fuel pricing over the past 15 years or so and conclude that prices will only increase to reflect increased operating costs and will not reflect the cost of capital. In fact, the rate of return on refining assets has been poor over the past 15 years and until recently, there has been a steady decline in the number of refineries operating in the U.S. However, this may have been due to a couple of circumstances specific to that time period. One, refinery capacity utilization was less than 80 percent in 1985. Two, at least regarding gasoline, the oxygen mandate for reformulated gasoline caused an increase in gasoline supply despite low refinery utilization rates. While this led to healthy financial returns for oxygenate production, it did not help refining profit margins.

Today, refinery capacity utilization in the U.S. is generally considered to be at its maximum sustainable rate. There are no regulatory mandates on the horizon which will increase production capacity significantly, even if ethanol use in gasoline increases substantially.[M] Consistent with this, refining margins have been much better over the past two and a half years than during the previous 15 years and the refining industry itself is projecting good returns for the foreseeable future.

Conclusions: Therefore, consistent with our findings made during the 2007 highway diesel rule, we do not expect this proposed rule to cause any supply shortages of nonroad, locomotive and marine diesel fuel.

5.9 Desulfurization Effect on Other Non-Highway Diesel Fuel Properties

5.9.1 Fuel Lubricity

Engine manufacturers depend on diesel fuel lubricity properties to lubricate and protect moving parts within fuel pumps and injection systems for reliable performance. Unit injector systems and in-line pumps, commonly used in diesel engines, are actuated by cams lubricated with crankcase oil, and have minimal sensitivity to fuel lubricity. However, rotary and distributor type pumps, commonly used in light and medium-duty diesel engines, are completely fuel lubricated, resulting in high sensitivity to fuel lubricity. The types of fuel pumps and injection systems used in nonroad diesel engines are the same as those used in highway diesel vehicles. Consequently, nonroad and highway diesel engines share the same need for adequate fuel lubricity to maintain fuel pump and injection system durability.

The state of California currently requires the use of the same diesel fuel in nonroad equipment as in highway equipment. Outside of California, highway diesel fuel is often used in nonroad equipment when logistical constraints or market influences in the fuel distribution system limit the availability of high sulfur fuel. Thus, nonroad equipment has been using federal 500 ppm sulfur diesel fuel and California diesel fuel, some of which may have been treated with

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[M] Both houses of the U.S. Congress are considering bills which would require the increased use of renewables, like ethanol, in gasoline and diesel fuel. While the amount of renewables could be considerable, it is well below the annual growth in transportation fuel use.

lubricity additives for nearly a decade. During this time, there has been no indication that the level of diesel lubricity needed for fuel used in nonroad engines differs substantially from the level needed for fuel used in highway diesel engines.

Diesel fuel lubricity concerns were first highlighted during the implementation of the federal 500 ppm sulfur highway diesel program and the state of California's diesel program circa 1993.[41] The diesel fuel requirements in the state of California differ from the federal requirements by substantially restricting the aromatics content of diesel fuel in addition to the sulfur content. Considerable research remains to be performed to better understand which fuel components are most responsible for fuel lubricity. Nevertheless, there is evidence that the typical process used to reduce diesel fuel sulfur content or aromatics content of diesel fuel, i.e. hydrotreating, can reduce fuel lubricity. Consequently, the implementation of the proposed sulfur standards would likely require that some action be taken to maintain the lubricity of non-highway diesel fuel.

The potential impacts on fuel lubricity from adoption of NRLM sulfur standards that we are proposing are associated solely with the additional refinery processing that would be necessary to meet these standards. Although we are proposing to extend the cetane index/aromatics content specification to NRLM diesel fuel, we do not expect that this would have a significant impact on fuel lubricity. EPA requires that highway diesel fuel meet a minimum cetane index level of 40 or, as an alternative contain no more than 35 volume percent aromatics. ASTM already applies a cetane number specification of 40 to NRLM diesel fuel, which in general is more stringent than the similar 40 cetane index specification. Because of this, the vast majority of current NRLM diesel fuel already meets the EPA cetane index/aromatics specification for highway diesel fuel. Thus, the proposed requirement would have an actual impact only on a limited number of refiners and there would be little overall impact on other diesel fuel qualities (including fuel lubricity) associated with producing fuel to meet the proposed cetane/aromatic requirement.

Blending small amounts of lubricity-enhancing additives increases the lubricity of poor-lubricity fuels to acceptable levels. These additives are available in today's market, are effective, and are in widespread use around the world. Several commenters on our final rule setting a 15ppm sulfur standard for highway diesel fuel indicated that biodiesel can be used to increase the lubricity of conventional diesel fuel to acceptable levels. Some testing suggested that only two volume percent would be necessary. However, more testing may be required to determine the necessary level of biodiesel for fuels not yet being produced, such as the 15ppm fuel being proposed today.

In the United States, there is no government or industry standard for diesel fuel lubricity. Therefore, specifications for lubricity are determined by the market. Since the beginning of the 500 ppm sulfur highway diesel program in 1993, fuel system producers, engine and engine manufacturers, and the military have been working with the American Society for Testing and Materials (ASTM) to develop protocols and standards for diesel fuel lubricity in its D-975 specifications for diesel fuel. ASTM is working towards a single lubricity specification that would be applicable to all diesel fuel used in any type of engine. Although ASTM has not yet adopted specific protocols and standards, refiners that supply the US market have been treating diesel fuel with lubricity additives on a batch to batch basis, when poor lubricity fuel is expected. Other evidence of how refiners are ensuring adequate fuel lubricity can be found in Sweden, Canada, and the U.S. military. The U.S. military has found that traditional corrosion inhibitor additives have been highly effective in reducing fuel system component wear. Since 1991, the use of lubricity additives in Sweden's 10 ppm sulfur Class I fuel and 50 ppm sulfur Class II fuel has resulted in acceptable equipment durability.[42] Since 1997, Canada has required that its 500 ppm sulfur diesel fuel not meeting a minimum lubricity be treated with lubricity additives.

The potential need for lubricity additives in diesel fuel meeting a 15 ppm sulfur specification was evaluated during the development of EPA's highway diesel rule. The final highway diesel rule did not establish a lubricity standard for highway diesel fuel. We believe the issues related to the need for diesel lubricity in fuel used in non-highway diesel engines are not substantially different from the those related to the need for diesel lubricity for highway engines. Consequently, we are relying on the same industry-based voluntary approach to ensuring adequate lubricity in non-highway diesel fuels that we relied upon for highway diesel fuel. Consistent with the highway diesel final rule, we believe the best approach is to allow the industry and the market to address the lubricity issue in the most economical manner. We expect that a voluntary approach would provide adequate customer protection from engine failures due to low lubricity, while providing the maximum flexibility for the industry. We expect that the American Society for Testing and Materials (ASTM) will finalize a fuel lubricity standard for use by industry that could be applied to low sulfur NRLM diesel fuel.

The degree to which removing the sulfur content from diesel fuel may impact fuel lubricity depends on the characteristics of the blendstocks used as well as the severity of the treatment process. Based on our comparison of the blendstocks and processes used to manufacture non-highway diesel engine fuels, we project that the potential decrease in the lubricity of non-highway diesel fuel that might result from the adoption of the proposed sulfur standards would be substantially the same as that experienced in desulfurizing highway diesel fuel to meet the same sulfur standard.

A refiner of diesel fuel for use in California and for much of the rest of the United States as well evaluated the impacts on fuel lubricity of the current federal and California diesel fuel requirements.[43] This refiner concluded that, reducing the aromatics content of diesel fuel requires more severe hydrotreating than reducing the sulfur content to meet a 500 ppm standard. Consequently, concerns regarding diesel fuel lubricity have primarily been associated with California diesel fuel and some California refiners treat their diesel fuel with a lubricity additive as needed. The subject refiner stated that outside of California, hydrotreating to meet the current 500 ppm sulfur specification seldom results in a sufficient reduction in fuel lubricity to require the use of a lubricity additive. We expect that the same hydrotreating process used to produce highway diesel fuel today would be used to reduce the sulfur content of non-highway diesel engine fuel to meet the 500 ppm sulfur standard during the first step of the proposed program. Therefore, we estimate that there would only a marginal increase in the use of lubricity additives in NRLM diesel fuel meeting the proposed 500 ppm sulfur standard for 2007.

The highway diesel program projected that hydrotreating would be the process most frequently used to meet the 15 ppm sulfur standard for highway diesel fuel in 2006. However, we project that the 2010 implementation date for the proposed 15 ppm standard for nonroad diesel fuel would allow the use of advanced technologies to remove sulfur from 80 percent of the affected nonroad diesel pool. The use of such developing desulfuriztion processes is discussed in 5.5 of this Draft RIA. These new processes have less of a tendency to affect other fuel properties than does hydrotreating. Therefore, the use of such new desulfurization technologies might tend to have less of an impact on fuel lubricity. However, we have no specific information with which to quantify the impacts of the developing technologies on fuel lubricity. To provide a conservatively high estimate of the potential impact of meeting the proposed 15 ppm standard for nonroad diesel fuel, we assumed that the potential impact on fuel lubricity of the new desulfurization processes would be the same as that experienced when hydrotreating diesel fuel to meet a 15 ppm sulfur standard. We therefore assumed, as we did for 15 ppm highway diesel fuel, that all 15 ppm NRLM diesel fuel would have to be treated with lubricity additives. The cost associated with the increased use of lubricity additives in 500 ppm NRLM diesel fuel in 2007 and in 15 ppm nonroad diesel fuel in 2010 is discussed in chapter 7 of this Draft RIA.

5.9.2 Volumetric Energy Content

Some of the desulfurization processes that we project would be used to meet the proposed non-highway diesel sulfur standards tend to reduce the volumetric energy content (VEC) of the fuel during processing. Desulfuization also tends to result in a swell in the total volume of fuel. These two effects tend to cancel each other out so that there is no overall loss in the energy content in a given batch of fuel that is subjected to desulfurization. Thus, we do not expect that the potential reduction in VEC which might result from the proposed sulfur standards would affect the ability of refiners to supply sufficient quantities of non-highway diesel fuel. The potential impacts on diesel supply are discussed in 5.8 of this Draft RIA.

However, since a greater volume of fuel must be consumed in the engine to produce the same amount of power, a larger volume of fuel would need to be distributed to meet the same level of demand. The potential increase in the distribution costs associated with a reduction in non-highway diesel VEC is discussed in 7.3.

The impact of desulfurization on diesel fuel VEC varies depending on the type of blendstocks and desulfurization process used. A comparison of the blendstocks used to produce non-highway diesel fuel with those used to produce highway diesel fuel is contained in 5.2 of this Draft RIA. Based on this comparison, we believe a comparable level of severity in the desulfurization process would be required to produce non-highway diesel fuel meeting a given sulfur specification as would be required to produce highway diesel fuel meeting the same sulfur specification. Refiners with experience in the use of hydrodesulfurization to manufacture both 500 ppm and 15 ppm highway diesel fuel provided us with confidential information that we used to estimate the accompanying reduction in VEC. Using this information, we estimated that hydrodesulfurization of non-highway diesel fuel to meet a 500 ppm sulfur standard would result in a reduction in volumetric energy content of 0.7 percent.

The proposed 15 ppm sulfur standard for nonroad diesel fuel would not be implemented until 2010. The additional lead-time would allow a number of refiners to take advantage of several less-expensive desulfurization technologies currently under development to meet the proposed 15 ppm nonroad diesel sulfur standard in addition to hydrodesulfurization (see section 5.3). The new desulfurization technologies also have less of an impact on diesel fuel volumetric energy content than does hydrodesulfurization. Using the mix of desulfurization technologies we project would be available, we estimate that desulfurizing nonroad diesel fuel from 500 ppm to 15 ppm in 2010 as proposed would reduce the volumetric energy content by an additional 0.35 percent. Thus, reducing the sulfur content of nonroad diesel fuel from the current maximum 5,000 ppm sulfur cap to the proposed 15 ppm cap on sulfur content is estimated to result in a 1.1 percent reduction in VEC. The following table (5.9-1) provides a summary of the projections we used to estimate the impact of the proposed sulfur standards on VEC, including : 1) the percentage of the applicable non-highway diesel fuel pool that we expect would be desulfurized using each of the available desulfurization processes, and 2) the projected impact of each desulfurization process on VEC.

Table 5.9-1
Projections Used in Estimating the in Reduction in
Volumetric Energy Content Associated with Meeting the Proposed Sulfur Standards

Desulfurization Process[a]	Percent of Diesel Pool Desulfurized Using a Given Process to Meet the Applicable Sulfur Standard		Reduction in Volumetric Energy Content Associated with a Given Desulfurization Process	
	NR, L, & M[b] 500 ppm in 2007	NR 15 ppm in 2010	Reduction in Sulfur Content	
			HS[c] to 500 ppm	500 ppm to 15 ppm
Hydrodesulfurization	100 %	20 %	0.7%	0.7 %
S-Zorb Sulfur Adsorption	NA	40 %	NA	0.1 %
Linde Isotherming	NA	40 %	NA	0.4 %
Over-all Impact on VEC of All Desulfurization Processes Used	-	-	0.7%	0.4 %

[a] See section 5.3 of this Draft RIA regarding the use of hydrodesulurization , the Phillips S-Zorb Sulfur Adsorption process, and the Linde Isotherming process to meet the proposed sulfur standards.
[b] NR = nonroad diesel fuel, L = locomotive diesel fuel, and M = marine diesel fuel.
[c] HS refers to high-sulfur diesel fuel at the current uncontrolled average sulfur level of approximately 3400 ppm.

It is important to remember that the anticipated reduction in VEC discussed above would only apply to those gallons of nonroad diesel fuel that currently have a high sulfur content. Due to logistical constraints in the fuel distribution system, much of the fuel used in non-highway engines meets highway diesel fuel standards (see section 7.1 of this Draft RIA). The costs related to the reduction in non-highway diesel fuel VEC that would accompany the adoption of the proposed sulfur standards are discussed in section 7.3 of this Draft RIA.

5.9.3 Fuel Properties Related to Storage and Handling

In addition to fuel lubricity additives, a range of other additives are also sometimes required in diesel fuel to compensate for deficiencies in fuel quality. These additives include cold flow improvers, static dissipation additives, anti-corrosion additives, and anti-oxidants. The highway diesel fuel program projected that, except for an increase in the fuel lubricity additives, reducing the sulfur content of highway diesel fuel to meet a 15 ppm standard would not result in an increase in the use of diesel performance additives. Since that time, we have identified no new information which would alter that projection. Consequently, our estimate of the increase in additive use that would result from the adoption of today's proposed rule parallels that under the highway program. We estimate that the use of lubricity additives would increase, and that the use of other additives would be unaffected.

5.9.4 Cetane Index and Aromatics

We are proposing that nonroad, locomotive and marine diesel fuel would need to comply with the current highway diesel fuel requirements for cetane index or aromatics. Thus, these non-highway diesel fuels would have to meet either a 40 minimum cetane index, or a 35 maximum aromatics limit. In this subsection, we present information on what these properties are currently for nonhighway diesel fuel, then we estimate how much they are likely to change when these streams are desulfurized.

We have reports of non-highway diesel fuel cetane index values from refinery samples during the years 1997 through 2001. The 1997 and 1998 reports were published by the National Institute for Petroleum and Energy Research (NIPER), Bartlesville, OK, and then this organization changed their name to TRW Petroleum Technologies, which published the 1999 - 2001 reports. The reports divided the country into the Eastern, Southern, Central, Rocky Mountain, and Western Regions. The samples, which averaged about 17 per year, were pooled from the various regions. The range of cetane index values for the 85 total samples is 39.4 - 57.0. Out of the 85 samples 5, or 6 percent, were under the cetane index value of 40 and potentially would not comply with the proposed cetane index minimum of 40. However, those that were below the 40 cetane index proposed minimum, were barely below it (i.e. 39.4 versus 40). Since the aromatics levels were not provided for these 5 samples, we could not verify if these samples would also not comply with the aromatics part of the specification.

As refiners desulfurize their non-highway diesel fuel to comply with the 500 ppm cap standard in 2007 and then again to comply with the 15 ppm cap standard in 2010, they would be expected to experience an increase in the cetane levels of their non-highway diesel fuel. Vendors of the desulfurization technologies either provided information on the impact that their technologies have on the cetane index of diesel fuel, or we were able to calculate the impact using changes to API gravity and the T-50 distillation point. While the changes in cetane index were provided for the desulfurization of highway diesel fuel, they are applicable to non-highway diesel fuel as well as it is similar in quality and composition to highway diesel fuel. The estimated impact of the desulfurization technologies on cetane index summarized in the following table. As described in Chapter 7 of the Draft RIA, much of the high sulfur diesel pool is already hydrotreated (on the order of 50 percent in some PADDs) and would therefore not be impacted by the first step of fuel control to 500 ppm, so the cetane index is expressed as a range for the high sulfur to 500 ppm step. The lower value of the range reflects that refiners would only have to hydrotreat half of their existing high sulfur pool to produce 500 ppm sulfur fuel, while the upper value reflects that refiners would have to treat their entire pool. For conventional hydrotreating, a range in the amount of increase in cetane index values is also reflected in the 500 ppm to 15 ppm sulfur reduction step which reflects the different estimates for the two vendors which provided us the desulfurization information.

Table 5.9-2
Impact of Desulfurization Technologies on Diesel Fuel Cetane Index

	Conventional Hydrotreating	Linde Isotherming	Phillips S-Zorb
High Sulfur to 500 ppm	+2 to +4	+2 to +4	Very Small
500 ppm to 15 ppm	+1 to +2	+2	Very Small
Total High Sulfur to 15 ppm	+3 to +6	+4 to +6	Small

As summarized in the above table, conventional hydrotreating improves the cetane index of diesel fuel by 2 to 4 numbers for the 500 ppm sulfur cap standard, and 1 to 2 numbers for the 15 ppm sulfur cap standard incremental to the 500 ppm standard. If the lowest cetane index values of non-highway diesel fuel are indeed between 39 and 40 as the NIPER/TRW data suggests, then the desulfurization of that pool to comply with the 500 ppm sulfur standard, which is expected to be accomplished using conventional desulfurization technology, is expected to increase the cetane index to a value above the 40 minimum, thus refiners are not expected to be constrained by the a cetane index requirement.

Aromatics would also be expected to decrease, although this decrease is expected to occur mostly through the saturation of polynuclear aromatics to monoaromatics. The biggest decrease in aromatics is expected by conventional hydrotreating and Linde Isotherming. Phillips S-Zorb probably only reduces aromatics a minimal amount.

5.9.5 Other Fuel Properties

Desulfurization is expected to impact other qualities of non-highway diesel fuel. The concentration of nitrogen in current high sulfur diesel fuel is on the order of several hundred parts per million. The desulfurization technologies projected to be used in the cost analysis for compliance with the 500 ppm sulfur cap standard are expected to lower nitrogen levels down to under 100 ppm, although they may still be above 50 ppm. These same desulfurization technologies are expected to lower nitrogen levels down to under 10 ppm for compliance with the 15 ppm sulfur cap standard.

Conventional desulfurization and Linde Isotherming are expected to affect the distillation temperature of non-highway diesel fuel. For desulfurizing high sulfur diesel fuel down to 15 ppm, one vendor of conventional hydrotreating technology estimates that each distillation point (T-10 - T-90) would experience a 5 degree fahrenheit decrease. Consistent with that, API gravity would be expected to increase by 4 numbers, thus, density would experience a commensurate decrease. Linde Isotherming is expected to impact the distillation temperature less than conventional hydrotreating due to the lower API gravity increase caused by Linde compared to conventional hydrotreating. Phillips S-Zorb would likely not impact the distillation temperature.

5.10 Feasibility of the Use of a Marker in Heating Oil from 2007-2010 and in Locomotive and Marine Fuel from 2010-2014

We are proposing that the solvent yellow 124 marker be used in heating oil at a concentration of 6 milligrams per liter from June 1, 2007 through June 1, 2010. The marker would be required to be added to heating oil at the refinery gate just as visible evidence of the red dye is required today. Beginning June 1, 2010, the same marker at the same concentration would be required to be added to locomotive and marine diesel fuel until June 1, 2014.After June 1, 2014, our proposal would not require the use of a marker. Any fuel with a marker concentration of greater than 0.1 mg per liter would be precluded from use in NRLM equipment prior to 2010 and NR equipment after 2010.

Following is a discussion of our evaluation of the feasibility of the use of yellow solvent 124 as the specified fuel marker under the proposed NRLM fuel program and our rationale for selecting solvent yellow 124. The potential impacts of the proposed marker requirements on the fuel distribution system are contained in section 5.4 of this draft RIA. The costs associated with the proposed marker are discussed in section 7.3 of this draft RIA.

The qualification criteria for a marker under the proposed NRLM program include:

1) Solubility in diesel fuel under the range of conditions experienced in the distribution system from the refinery to the end-user.
2) Not naturally present in diesel fuel
3) Chemical stability under the range of conditions that can be experienced during storage and distribution of diesel fuel
4) Difficult to remove from fuel or obscure presence to avoid detection
5) Presence in fuel is positively identifiable using laboratory and field tests
6) Detectable in very small concentrations to reveal mixtures of marked and unmarked fuels
7) Economic acceptability, ready availability, and ease of application
8) No increased public health risk

There are a number of types of dyes and markers. Visible dyes are most common, are typically least expensive, and are easily detected in the field. Laboratory tests are often also available for such dyes to quantify the concentration of the dye present in fuel. This is the case with red dye 164 which is required by the U.S. IRS to be present in non-taxed diesel fuel at a minimum level that is spectrally equivalent to 3.9 pounds per thousand barrels (ptb) of the IRS-specified standard solvent red 26 dye. The longtime presence of a number of visible dyes in fuels means that their acceptability under the above qualification criteria has been well established.

However, using a second diesel dye for segregation of heating oil based on visual identification is problematic. Most dye colors that provide a strong visible trace in fuels are already in use for different fuel applications. More importantly, mixing two fuels containing different strong dyes can result in interference between the two dyes rendering identification of the presence of either dye difficult. Yet, the mixing of nonroad diesel fuel into heating oil for eventual sale as heating oil would be an acceptable and often an economically desirable practice. Furthermore, to avoid interfering with the IRS tax code, it would be advantageous to maintain the current red color. Based on these considerations, we believe that the use of a second strong dye to visibly segregate heating oil from NRLM is not practicable.

Fuel markers that do not depend on a visible trace for detection are beginning to see more use in branded fuels. Invisible markers are typically somewhat more expensive than visible markers. Soluble dyes have also been used at a concentration too low to allow reliable detection of their presence visually but that does allow detection by other means. When a dye is used in this fashion it is more appropriate to refer to it as a marker, since its functionality is not associated with the slight color it may impart to the fuel. Fuel markers typically have a simple method to detect the presence of the marker in the field and a more rigorous method the quantify the concentration of the marker in the fuel which must be conducted in the laboratory. Such laboratory methods are favored for developing strong evidence of noncompliance for use in enforcement actions.

Depending on the marker type, detection in the field is accomplished either by the addition of a chemical reagent or by their fluorescence when subjected to near-infra-red or ultraviolet light. Some chemical-based detection methods are more suitable for use in the field than others. For example, some are more suited for laboratory use due to the complexity of the detection process or concerns regarding the toxicity of the reagents used to reveal the presence of the marker. Ideally, after conducting a field test for the presence of the marker and finding the fuel to be compliant, the inspector returns the fuel sample to the fuel batch or otherwise ensures that it is used for the intended fuel purpose. This practice avoids the difficulty associated with disposing of the fuel sample. For most types of field tests for markers, however, this practice is not be possible. The introduction of the reagent to the test fuel sample typically makes returning the returning the fuel sample for its intended use impossible, and it must be disposed of by other means. The toxicity of the by-products from testing can also be a concern. Chemical-based field tests are typically inexpensive. However, if such tests produce toxic by-products, the cost of disposing of such by-products can be significant. In addition, there are public health concerns related to the potential improper disposal of such by-products.

Near-infra-red and ultra-violet flourescent markers can be easily detected in the field using a small device that requires only brief training for the operator and leaves that sample unaffected. Therefore, concerns regarding test reagents and by-products are not an issue and the fuel sample can be returned to the fuel batch. However, the devices used in the field detection of such markers can be more expensive..

There are also more exotic markers available such as based on immunoassay, and isotopic or molecular enhancement. Such markers typically can only be detected by laboratory analysis and are more expensive than the markers discussed above. Because of the lack of a easy field test, we believe that further consideration of the use of such markers for the proposed purpose is not warranted.

The Euromarker:

Effective in August 2002, the European Union (EU) enacted a marker requirement for diesel fuel that is taxed at a lower rate (which applies in all of the EU member states).[44] The marker selected by the EU is N-ethyl-N-[2-[1-(2-methylpropoxy)ethoxyl]-4-phenylazo]-benzeneamine.[45] This compound is also referred to as solvent yellow 124 or the Euromarker. The treatment level required by the EU is 6 milligrams per liter. Despite its name, solvent yellow 124 does not impart a strong color to diesel fuel when used at the proposed concentration. The EU allows its member states to choose which visible dye to use in lower-taxed fuel in addition to the Euromarker. A number of countries in the EU use a red dye.[46] The Euromarker imparts a slight orange shade to fuel that is dyed red. However, experience of the EU members has shown the fuel containing red dye and the Euromarker is still recognizable as red dyed diesel fuel.[47] The specific type of red dye used in Europe is not the same type used in the U.S. Nevertheless, we believe that the experience of EU member states that the Euromarker does not interfere with the identification of the presence of strong red dyes in diesel fuel is sufficiently predictive of its potential impact on the color that the IRS red dye impart to diesel fuel. Therefore, we do not expect that the presence of solvent yellow 124 in diesel fuel that contains the IRS-specified red dye would interfere with the use of the red dye by IRS to identify non-taxed fuels.

Solvent yellow 124 is substantially similar to diesel fuel and is registered under EPA's Fuel and Fuel Additive program which evaluates an additive's suitability for use based on the potential effects on human health and vehicle emissions performance. In addition, extensive evaluation and testing of the Euromarker was conducted by the European Commission. This included combustion testing which showed no detectable difference between the emissions from marked and unmarked fuel. We also understand that Norway specifically evaluated the use of distillate fuel containing the Euromarker for heating purposes and determined that the presence of the Eurmarker did not cause an increase in harmful emissions from heating equipment. Based on the European experience with the Euromarker , we do not expect that there would be concerns regarding the compatibility of the Euromarker in the U.S. fuel distribution system or for use in motor vehicle engines and other equipment such as in residential furnaces. The European Union intends to review the use of Euromarker after December 2005, or earlier if any health and safety or environmental concerns about its use are raised. We intend to keep abreast of such activities and may initiate our own review of the use of the Euromarker depending on the European Union's findings.

Fuel additives are typically required to be tested for their suitability for use under the unique conditions present in aircraft engines and fuel supply systems before they are allowed to be present in jet fuel. Due to safety concerns, jet fuel is held to very strict standards regarding the allowable presence of contaminants and additives that are not specifically allowed for use in jet fuel. For example, the Department of Defense (DoD) maintains a zero-tolerance for any contamination of jet fuel with the red dye required by the IRS (and EPA). Given their past experience with red dye, DoD raised concerns regarding the extent to which jet fuel might become contaminated with solvent yellow 124 due to the presence of solvent yellow 124-containing fuels and jet fuel in the U.S. common carrier pipeline distribution system, and whether any such contamination might be cause for concern.

We do not believe that there any significant pathways for such contamination to take place other than by potential human error. In addition, the fact that the fuel distribution industry in the U.S. has been successful in managing contamination of jet fuel with red dye indicates that the potential contamination of jet fuel with the solvent yellow 124 can also be successfully managed in the US fuel distribution system. Therefore, we believe that our proposed use of solvent yellow 124 should not pose a significant risk to the maintenance of jet fuel purity.

There is currently no official procedure recognized by the European Union to quantify the presence of the Euromarker in distillate fuels. The most commonly accepted method used in the European Community is based on the chemical extraction of the Euromarker using hydrochloric acid solution and cycloxane, and the subsequent evaluation of the extract using a visual spectrometer to determine the concentration of the Euromarker.[48] This test is inexpensive and easy to use for field inspections. However, the test involves reagents that require some safety precautions and the small amount of fuel required in the test must be disposed of as hazardous waste. Nevertheless, we believe that such safety concerns are manageable here in the U.S. just as they are in Europe and that the small amount of waste generated can be handled along with other similar waste generated by the company conducting the test, and that the associated effort/costs would be negligible.

Similar to the approach proposed regarding the measurement of fuel sulfur content, we are proposing a performance based procedure to measure the concentration of solvent yellow 124 in distillate fuel. Under the performance-based approach, a given test method could be approved for use in a specific laboratory or for field testing by meeting certain precision and accuracy criteria. There would be no designated marker test method. Properly selected precision and accuracy values potentially would allow multiple methods and multiple commercially available instruments to be approved, thus providing greater flexibility in method and instrument selection while also encouraging the development and use of better methods and instrumentation in the future. For example, we are hopeful that with more time and effort a simpler test can be developed that can avoid the use of reagents and the generation of hazardous waste that is by product of the current commonly accepted method.

In developing the precision and accuracy criteria for the sulfur test method, EPA drew upon the results of an interlaboratory study conducted by the American Society for Testing and

Materials (ASTM) to support ASTM's standardization of the sulfur test method. Unfortunately, there has not been sufficient time for industry to standardize the test procedure used to measure the concentration of solvent yellow 124 (Euromarker) in distillate fuels or to conduct an interlaboratory study regarding the variability of the method. Nevertheless, the European Union has been successful in implementing its Euromarker requirement while relying on the marker test procedures which are currently available. As referenced above, the most commonly accepted method used in the European Union is a visual spectrometer-based procedure. We are proposing to use this procedure to establish the precision and accuracy criteria on which a marker test procedure would be approved under the performance based approach..

There has been substantial experience in the use of the proposed reference market test method since the August 2002 effective date of the European Union's Euromarker requirement. However, EPA is aware of only limited summary data on the variability of the reference test method from a manufacturer of the visible spectrometer apparatus used in the testing.[49] The stated resolution of the test method from in the materials provided by this equipment manufacturer is 0.1 mg/L, with a repeatability of plus or minus 0.08 mg/L and a reproducibility of plus or minus 0.2 mg/L. In the lack of more extensive data, we are proposing to use these available data as the basis of our proposed precision and accuracy criteria as discussed below. The referenced repeatability and reproducibility are terms related to test variability used by ASTM in defining their voluntary consensus test standards. ASTM defines repeatability as the difference between successive results obtained by the same operator with the same apparatus under constant operating conditions on identical test materials that would, in the long run, in the normal and correct operation of the test method be exceeded only in one case in 20. Reproducibility is defined by ASTM as the difference between two single and independent results obtained by different operators working in different laboratories on identical material that would, in the long run, be exceeded only in one case in twenty.

The first qualification criterion, precision, refers to the consistency of a set of measurements and is used to determine how closely analytical results can be duplicated based on repeat measurements of the same material under prescribed conditions. To demonstrate the precision of a given marker test method under the performance-based approach, a laboratory facility would perform 20 repeat tests over several days on samples taken from a homogeneous supply of a commercially available diesel fuel that contains the marker. Using a similar methodology to that employed in deriving the proposed sulfur test procedure precision value, results in a precision value for the marker test procedure of 0.043 mg/L. This value was derived as follows:
0.43 mg/L is equal to 1.5 times the standard deviation (0.029) where the standard deviation is equal to the repeatability of the reference test method (0.08 mg/L) divided by 2.77. Since the conditions of the precision qualification test admit more sources of variability than the conditions under which ASTM repeatability is determined (longer time span, different operators, environmental conditions, etc.) the repeatability standard deviation derived from the repeatability value was multiplied by what we believe to be a reasonable adjustment factor, 1.5 to compensate for the difference in conditions.

We are concerned that the use of the 0.043 mg/L precision value derived above, because it is based on very limited data, might preclude the acceptability of test procedures that would be adequate for the intended regulatory use. In addition, the lowest measurement of marker concentration that would have relevance under the proposed regulations is 0.1 mg per liter. Consequently, we are proposing that the precision of a test procedure would need to be less than 0.1 mg/L for it to qualify.

The second criterion, accuracy, refers to the closeness of agreement between a measured or calculated value and the actual or specified value. To demonstrate the accuracy of a given test method under the performance-based approach, a laboratory facility would be required to perform 10 repeat tests, the mean of which could not deviate from the Accepted Reference Value (ARV) of the standard by more than 0.05 mg/L. We believe that the proposed accuracy level is not overly restrictive, while being sufficiently protective considering that the lowest marker level of regulatory significance would be 0.1 mg/L.

These tests would be performed using commercially available solvent yellow 124 standards. Ten tests would be required using each of two different marker standards, one in the range of 0.1 to 1 mg/L and the other in the range of 4 to 10 mg/L of solvent yellow 124. We selected the two ranges of the marker standards to cover the two marker concentrations that are of most regulatory concern: 6 mg/L is the minimum marker concentration required in fuels that we are proposing must contain the marker, while 0.1 mg/L is the maximum allowed concentration for fuel to be considered as not containing the fuel marker for the purposes of the fuel use restrictions on which the fuel marker requirements are based.

We believe that these precision and accuracy criteria would limit the allowed test procedures to those capable of satisfying the intended use for enforcement and affirmative defenses to presumptive liability purposes, while not being overly restrictive.

Solvent yellow 124 is marketed by several manufactures and is in current wide-scale use in the European community. We anticipate that these manufactures would have sufficient lead-time to increase their production of solvent yellow 124 to supply the increase in demand that would result from the proposed marker provisions.

The proposed treatment rate would ensure adequate detection in the distribution system even if diluted by a factor of 50. Removal of the marker is possible through an expensive laundering process. However, we believe that there would be little economic incentive to attempting to the remove the marker in the United States given that its removal would only allow the use of the fuel in other nontaxed applications. Even if the marker were removed, the IRS red dye would still be present to prevent the use of the fuel for highway (taxed) purposes.

Other Potential Candidate Fuel Markers:

We considered other potential markers that might be used to identify and segregate heating oil from NRLM fuel. One of the potential alternatives that we identified is the Clir-Code® marker system manufactured by ISOTAG Technologies Inc. The Clir-Code® marker system has been used extensively in U.S. fuel and includes a field test that employs a hand-held near infra-red detector which does not require the use of any reagents. EPA deferred proposing the use of the Clir-Code® marker because we believe that the advantage of a simpler field test would not compensate for the increased treatment cost relative to the use of the Euromarker

Appendix 5A: EPA's Legal Authority for Proposing Nonroad, Locomotive, and Marine Diesel Fuel Sulfur Controls

We are proposing diesel fuel sulfur controls under our authority in section 211(c)(1) of the Clean Air Act. This section gives us the authority to "control or prohibit the manufacture, introduction into commerce, offering for sale, or sale" of any fuel or fuel additive for use in a nonroad engine or vehicle (1) whose emission products, in the judgment of the Administrator, cause or contribute to air pollution which may reasonably be anticipated to endanger the public health or welfare or (2) whose emission products will impair to a significant degree the performance of any emission control device or system which is in general use, or which the Administrator finds has been developed to a point where in a reasonable time it would be in general use were the fuel control or prohibition adopted.

We currently do not have regulatory requirements for sulfur in nonroad, locomotive, or marine diesel fuel. Beginning in 1993, highway diesel fuel was required to meet a sulfur cap of 500 ppm and be segregated from other distillate fuels as it left the refinery by the use of a visible level of dye solvent red 164 in all non-highway distillate. Any fuel not dyed is treated as highway fuel.

We are proposing controls on sulfur levels in nonroad diesel fuel based on both of the Clean Air Act criteria described above. Under the first criterion, we believe that emission products of sulfur in nonroad, locomotive, and marine diesel fuel used in these engines contribute to PM and SOx pollution. As discussed in Chapter 2, emissions of these pollutants cause or contribute to ambient levels of air pollution that endanger public health and welfare. Control of sulfur to 500 ppm for this fuel will lead to significant, cost-effective reductions in emissions of these pollutants. Under the second criterion, we believe that sulfur in nonroad diesel fuel will significantly impair the emission-control systems expected to be in general use in nonroad engines designed to meet the proposed emission standards. Chapter 4 describes the substantial adverse effect of high fuel-sulfur levels on the emission-control devices or systems for diesel engines meeting the proposed emission standards. Controlling sulfur levels in nonroad diesel fuel to 15 ppm will enable emission-control technology that will achieve significant, cost-effective reduction in emissions of these pollutants. The following sections summarize our analysis of the various issues related to adopting fuel-sulfur controls for nonroad, locomotive, and marine diesel fuel.

5A.1 Health and Welfare Concerns of Air Pollution Caused by Sulfur in Diesel Fuel

At the current unregulated levels of sulfur in this diesel fuel, the emission products from the combustion of diesel sulfur in these engines can reasonably be anticipated to endanger public health and welfare. Sulfur in nonroad, locomotive and marine diesel fuel leads directly to emissions of SO2 and sulfate PM from the exhaust of diesel vehicles, both of which cause adverse health and welfare impacts, as described in Chapter 2. SO2 emissions from nonroad, locomotive and marine engines are directly proportional to the amount of sulfur in the fuel. SO2 is oxidized in the atmosphere to SO3 which then combines with water to form sulfuric acid (H2SO4) and further combines with ammonium in the atmosphere to form ammonium sulfate aerosols. These aerosols are what is often referred to as sulfate PM. This sulfate PM comprises a significant portion of the "secondary" PM that does not come directly from the tailpipe, but is nevertheless formed in the atmosphere from exhaust pollutants. Exposure to secondary PM may be different from that of PM emitted directly from the exhaust, but the health concerns of secondary PM are just as severe as for directly emitted particulate matter, with the possible exception of the carcinogenicity concerns with diesel exhaust.

Approximately 1-2% of the sulfur in nonroad, locomotive and marine diesel fuel is not converted into SO2, but is instead further oxidized into SO3 which then forms sulfuric acid aerosols (sulfate PM) as it leaves the tailpipe. While only a small fraction of the overall sulfur is converted into sulfate emissions in the exhaust, it nevertheless accounts for approximately 10% of the total PM emissions from diesel engines today. This sulfate PM is also directly proportional to the sulfur concentration in the fuel. The health and welfare implications of emissions of PM and SO2 and the need for reductions in these emissions are discussed in Chapter 2.

The proposed first step in the reduction in the sulfur level of nonroad, locomotive, and marine diesel fuel to 500 ppm would achieve approximately a 90 percent reduction in the emissions of SO2 and sulfate PM emissions from nonroad, locomotive, and marine diesel engines compared to today's levels. The proposed second step of nonroad sulfur control to 15 ppm (and the control of locomotive and marine diesel fuel also being considered) would achieve in excess of a 99 percent reduction in these pollutants. The rationale for the two-step approach to fuel sulfur control is discussed in Chapters 5 and 12. Aside from its dramatic and immediate in-use emission benefits, the proposed sulfur level of 500 ppm for the first step was chosen primarily due to its consistency with the current highway diesel fuel standard. The magnitude of the distribution system costs would virtually prohibit the widespread distribution of any other grades of diesel fuel, as discussed in Section IV.B of the preamble to the proposed rule. Consequently, the choice of sulfur level was limited to one of the existing three grades; 15 ppm, 500 ppm, or uncontrolled. A reduction in the sulfur directly to 15 ppm was inconsistent with the proposed 2-step approach to diesel fuel sulfur control. Therefore, given the need to achieve reductions, the 500 ppm level was selected for this temporary first step of control.

Section 211(c)(2)(A) requires that, prior to adopting a fuel control based on a finding that the fuel's emission products contribute to air pollution that can reasonably be anticipated to endanger public health or welfare, EPA consider "all relevant medical and scientific evidence available, including consideration of other technologically or economically feasible means of achieving emission standards under [section 202 of the Act]." EPA's analysis of the medical and scientific evidence relating to the emissions impact from nonroad, locomotive and marine engines, which are impacted by sulfur in diesel fuel, is described in more detail in Chapter 2.

EPA has also satisfied the statutory requirement to consider "other technologically or economically feasible means of achieving emission standards under section [202 of the Act]." This provision has been interpreted as requiring consideration of establishing emission standards under section 202 prior to establishing controls or prohibitions on fuels or fuel additives under section 211(c)(1)(A). See *Ethyl Corp. v. EPA*, 541 F.2d. 1, 31-32 (D.C. Cir. 1976). In *Ethyl*, the court stated that section 211(c)(2)(B) calls for good faith consideration of the evidence and options, not for mandatory deference to regulation under section 202 compared to fuel controls. *Id*. at 32, n.66.

EPA recently set emissions standards for heavy-duty highway diesel engines under section 202 (66 FR 5002, January 18, 2001). That program will reduce particulate matter and oxides of nitrogen emissions from heavy duty engines by 90 percent. In order to meet these more stringent standards for diesel engines, the program requires a 97 percent reduction in the sulfur content of diesel fuel. EPA does not believe it is appropriate to seek further reductions at this time from these engines. Also, section 211(c)(1)(A) refers to standard setting under section 202 for highway engines or vehicles, and does not refer to standard setting under section 213. In any case, EPA is proposing stringent new standards for nonroad diesel engines under section 213.

The nonroad, locomotive and marine diesel sulfur standards of 500 ppm proposed today represent an appropriate exercise of the Agency's discretion under section 211(c)(1)(A). The 500 ppm level is consistent with current highway diesel fuel (until 2010) and adopting the same level for nonroad, locomotive, and marine diesel fuels avoids costs associated with more grades of fuel in the distribution system. The 500 ppm level also will achieve significant and cost-effective environmental benefits, providing approximately 90 percent of the sulfate PM and SO2 benefits associated with control to 15 ppm. It also allows for a short lead time for implementation, enabling the environmental benefits to begin as soon as possible.

5A.2 Impact of Diesel Sulfur Emission Products on Emission-Control Systems

EPA is also proposing to restrict the sulfur content of nonroad diesel fuel nationwide to no more than 15 ppm, beginning in 2010 to enable compliance with new emission standards based on the use of advanced emission control technology that will be available to nonroad diesel engines. EPA believes that sulfur in nonroad diesel fuel would significantly impair the emission-control technology of nonroad engines designed to meet the proposed emission standards. We know that diesel sulfur has a negative impact on engine emission controls. This is not a new development. As discussed in Chapter 4, we believe existing aftertreatment technologies will be capable of achieving dramatic reductions in NOx and PM emissions from nonroad engines for the 2009 time frame. The aftertreatment technology for PM is already in an advanced state of development and being tested in fleet demonstrations in the U.S. and Europe. The NOx aftertreatment technology is in a less-advanced, but still highly promising state of development, and as discussed in Chapter 4, EPA believes the lead time between now and 2011 will provide ample opportunity to adapt this technology for feasible operation on nonroad engines. EPA believes these aftertreatment technologies would be in general use by 2009 and 2011, respectively, with the diesel sulfur controls proposed in this rule.

These aftertreatment technologies are ineffective in reducing NOx and PM emissions and incapable of being introduced widely into the marketplace at the nonroad diesel sulfur concentrations typical today or less. Not only does their efficiency at reducing NOx and PM emissions fall off dramatically at elevated fuel sulfur concentrations, but engine operation impacts and permanent damage to the aftertreatment systems are also possible. In order to ensure regeneration of the diesel particulate filter at exhaust temperatures typical of nonroad diesel engines as described in Chapter 4, we are expecting that significant amounts of precious group metals (primarily platinum) will be used in their washcoat formulations. There are two primary mechanisms by which sulfur in nonroad diesel fuel can limit the effectiveness or robustness of diesel particulate filters which rely on a precious metal oxidizing catalyst. The first is inhibition of the oxidation of NO to NO_2 and the second is the preferential oxidation of SO2 to SO3, forming a precursor to sulfate particulate matter. With respect to NOx aftertreatment, all of the NOx aftertreatment technologies discussed in Chapter 4 that EPA believes will generally be available to meet the proposed standards are expected to utilize platinum to oxidize NO to NO2 to either: improve the NOx reduction efficiency of the catalysts at low temperatures; or, as in the case of the NOx absorber, as an essential part of the process of NOx storage and regeneration. This reliance of NO2 as an integral part of the reduction process means that the NOx aftertreatment technologies, like the PM aftertreatment technologies, would be significantly impaired by the sulfur in nonroad diesel fuel. Sulfur, in the form of SOx, competes with NOx to be stored by the aftertreatment device. The resulting sulfate is harder to break down than the stored NOx, and is not normally released during the regeneration phase (i.e. SOx is stored preferentially to NOx by the device). The sulfur therefore continues to guild up, preventing storage of NOx, and rendering the device ineffective. Further, although this problem can be addressed by adding a “desulfation” phase to aftertreatment operation, the number of these desulfation events needs to be minimized in order to prevent damage to the aftertreatment device.

5A.3 Sulfur Levels that Nonroad Engines Can Tolerate

As discussed in Chapter 4, there are three key factors which when taken together lead us to conclude that a nonroad diesel sulfur cap of 15 ppm is necessary so the NOx and PM aftertreatment technology on nonroad engines will function properly and be able to meet the proposed emission standards. These factors, as discussed in more detail in Chapter 4, are the implications sulfur levels in excess of 15 ppm would have on the efficiency and reliability of the systems and their impact on the fuel economy of the engine.

The efficiency of emission control technologies at reducing harmful pollutants is directly impacted by sulfur in nonroad diesel fuel. Initial and long term conversion efficiencies for NOx, HC, CO and diesel PM emissions are significantly reduced by catalyst poisoning and catalyst inhibition due to sulfur. NOx conversion efficiencies with the NOx adsorber technology in particular are dramatically reduced in a very short time due to sulfur poisoning of the NOx storage bed. In addition, total PM control efficiency is negatively impacted by the formation of sulfate PM. The formation of sulfate PM is likely to be in excess of the total PM standard proposed today, unless nonroad diesel fuel sulfur levels are below 15 ppm. When sulfur is kept at these low levels, both PM and NOx aftertreatment devices are expected to operate at high levels of conversion efficiency, allowing compliance with the PM and NOx emission standards.

The reliability of the emission control technologies to continue to function as required under all operating conditions for the life of the engine is also directly impacted by sulfur in nonroad diesel fuel. As discussed in Chapter 4, sulfur in nonroad diesel fuel can prevent proper operation and regeneration of both NOx and PM advanced aftertreatment control technologies leading to permanent loss in emission control effectiveness and even catastrophic failure of the systems. For example, if regeneration of a PM filter does not occur, catastrophic failure of the filter could occur in less than a single tank full of high sulfur nonroad diesel fuel. For NOx adsorbers, keeping sulfur levels no higher than 15 ppm is needed to minimize the number of desulfation events to provide a high efficiency operation over the useful life of the engine. It is only through the availability of nonroad diesel fuel with sulfur levels less than 15 ppm that the reliability of these technologies can be raised to the point where they become feasible for successful use by nonroad engines. We believe that diesel fuel sulfur levels of 15 ppm are needed and would allow these technologies to operate properly throughout the life of the vehicle, including proper periodic or continuous regeneration.

The sulfur content of nonroad diesel fuel will also impact the fuel economy of nonroad engines equipped with NOx and PM aftertreatment technologies. As discussed in detail in Chapter 4, NOx adsorbers are expected to consume nonroad diesel fuel in order to cleanse themselves of stored sulfates and maintain efficiency. The larger the amount of sulfur in nonroad diesel fuel, the greater this adverse impact on fuel economy. As sulfur levels increase above 15 ppm the fuel economy impact transitions quickly from merely noticeable to unacceptable. Likewise PM trap regeneration is inhibited by sulfur in nonroad diesel fuel. This leads to increased PM loading in the diesel particulate filter, increased exhaust backpressure, and poorer fuel economy. Thus for both NOx and PM technologies, the lower the fuel sulfur level the better the fuel economy of the vehicle.

As a result of these factors, we believe that 15 ppm represents an upper threshold of acceptable nonroad diesel fuel sulfur levels and are therefore proposing to cap in-use sulfur levels there.

5A.4 Sulfur Sensitivity of Other Catalysts

Section 211(c)(2)(B) requires that, prior to adopting a fuel control based on a significant impairment to vehicle emission-control systems, EPA consider available scientific and economic data, including a cost benefit analysis comparing emission-control devices or systems which are or will be in general use that require the proposed fuel control with such devices or systems which are or will be in general use that do not require the proposed fuel control. As described below, we conclude that the aftertreatment technology expected to be used to meet the proposed nonroad standards would be significantly impaired by operation on high sulfur nonroad diesel fuel. Our analysis of the available scientific and economic data can be found elsewhere in this document, including an analysis of the environmental benefits of the proposed control (Chapter

3), an analysis of the costs and the technological feasibility of controlling sulfur to the proposed levels (Chapter 7), and a cost-effectiveness analysis of the proposed sulfur control and nonroad emission standards (Chapter 8). Under section 211(c)(2)(B), EPA is also required to compare the costs and benefits of achieving emission standards through emission-control systems that would not be sulfur-sensitive, if any such systems are or will be in general use.

We have determined that there are not (and will not be in the foreseeable future) emission control devices available for general use in nonroad engines that can meet the proposed nonroad emission standards and would not be significantly impaired by nonroad diesel fuel with high sulfur levels. NOx and PM emissions cannot be reduced anywhere near the magnitude contemplated by the standards proposed today without the application of aftertreatment technology. As discussed in Chapter 4, there are a number of aftertreatment technologies that are currently being developed for both NOx and PM control with varying levels of effectiveness, sulfur sensitivity, and potential application to nonroad engines.

As discussed in Chapter 4, all of the aftertreatmrent technologies that could be used to meet the PM or NOx standards are significantly impaired by the sulfur in diesel fuel. For PM control, EPA is not aware of a PM aftertreatment technology that is capable of meeting the PM standard adopted today and that would not need the level of sulfur control adopted in this rule. In addition, the NOx aftertreatment technologies evaluated by EPA all rely on the use of catalytic processes to increase the effectiveness of the device in reducing NOx emissions. For example both NOx adsorbers and compact SCR would rely on noble metals to oxidize NO to NO2, to increase NOx conversion efficiency at the lower exhaust temperatures found in diesel motor vehicle operation. This catalytic process, however, produces sulfate PM from the sulfur in the diesel fuel, and these NOx aftertreatment devices need the level of sulfur control adopted in this rule in order for the vehicle to comply with the PM standard.

In addition, compact SCR is not a technology that would be generally available by the model year 2011 time frame. Significant and widespread changes to the fuel distribution system infrastructure would have to be made and in place by then, and there is no practical expectation that this would occur, with or without the low sulfur standard adopted today. While it is feasible and practical to expect that compact SCR may have a role in specific controlled circumstances, such as certain centrally fueled fleets, it is not realistic at this time to expect that the fuel distribution system infrastructure changes needed for widespread and general use of compact SCR on nonroad engines will be in place by the model year 2011 time frame. In addition, even if SCR were used to obtain the emission performance required by today's standards, it is not clear that the vehicles would continue to maintain that level of performance in-use. Finally, for NOx control, both NOx adsorbers and compact SCR are significantly impaired by sulfur in diesel fuel, and both technologies would need very large reductions in sulfur from current levels to meet the NOx standard adopted today. EPA believes that the requirement of a cost benefit analysis under section 211(c)(2)(B) is not aimed at evaluating emission-control technologies that would require significant additional or different EPA fuel control regulations before the technology could be considered generally available.

In sum, EPA believes that both PM and NOx aftertreatment technologies require the level of sulfur control adopted today to meet the PM standards. There is no PM or NOx emission-control device or system that would be in general use that does not need this level of sulfur control for purposes of controlling PM. EPA also believes that the only NOx aftertreatment technologies that would be considered generally available for use to meet the NOx standard. need the level of sulfur adopted today to be considered generally available for use to meet the NOx standard.

As described in Chapter 4, EPA anticipates that all the nonroad engine technologies expected to be used to meet the final nonroad standards will require the use of low sulfur nonroad diesel fuel. If we do not control diesel sulfur to the finalized levels, we would not be able to set nonroad standards as stringent as those we are finalizing today. Consequently, EPA concludes that the benefits that would be achieved through implementation of the engine and sulfur control programs cannot be achieved through the use of emission control technology that does not need the sulfur control adopted in this rule, and would be generally available to meet the emission standards adopted in this rule.

This also means that if EPA were to adopt emission standards without controlling diesel sulfur content, the standards would be significantly less stringent than those finalized today based on what would be technologically feasible with current or 500 ppm sulfur levels.

5A.5 Effect of Nonroad Diesel Sulfur Control on the Use of Other Fuels or Fuel Additives

Section 211(c)(2)(C) requires that, prior to prohibiting a fuel or fuel additive, EPA establish that such prohibition will not cause the use of another fuel or fuel additive “which will produce emissions which endanger the public health or welfare to the same or greater degree” than the prohibited fuel or additive. This finding is required by the Act only prior to prohibiting a fuel or additive, not prior to controlling a fuel or additive. Since EPA is not proposing to prohibit sulfur in nonroad, locomotive or marine fuel, but rather to control the levels of sulfur in these diesel fuels, this finding is not required prior to regulation. However, EPA does not believe that the proposed sulfur control will result in the use of any other fuel or additive that will produce emissions that will endanger public health or welfare to the same or greater degree as the emissions produced by nonroad diesel with uncontrolled sulfur levels.

Unlike in the case of unleaded gasoline in the past where lead was providing a primary function in providing the necessary octane for the vehicles to function properly, sulfur does not serve any useful function in nonroad, locomotive or marine diesel fuel. It is not added to diesel fuel, but comes naturally in the crude oil into which diesel fuel is processed. If it were not for the fact that it costs money to remove sulfur from diesel fuel, it would have been removed years ago to improve the maintenance and durability characteristics of diesel engines. EPA is unaware of any function of sulfur in nonroad, locomotive or marine diesel fuel that might have to be replaced once sulfur is removed, with the possible exception of lubricity characteristics of the fuel. As discussed in Chapters 4 and 5, there is some evidence to suggest that as sulfur is removed from diesel fuel the natural lubricity characteristics of diesel fuel may be reduced. Depending on the crude oil and the manner in which desulfurization occurs some low sulfur diesel fuels can exhibit poor lubricity characteristics. To offset this concern lubricity additives are sometimes added to the diesel fuel. These additives, however, are already in common use today and EPA is unaware of any health hazards associated with the use of these additives in diesel fuel and would merely be used in larger fractions of the diesel fuel pool. We do not anticipate that their use would produce emissions which would reduce the large public health and welfare benefits that this rule would achieve.

EPA is unaware of any other additives that might be necessary to add to nonroad, locomotive or marine diesel fuel to offset the existence of sulfur in the fuel. EPA is also unaware of any additives that might need to be added to nonroad, locomotive or marine diesel fuel to offset any other changes to the fuel which might occur during the process of removing sulfur. As we move forward with this rulemaking and its implementation we will continue to investigate this issue, and welcome any comment on it.

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7.1 Nonroad Fuel Volumes

7.1.1 Overview

This section describes how the estimates of diesel fuel demand for land-based nonroad engines, locomotives, and marine vessels, which will be directly affected by the proposed rules, were determined. Volumes are provided for various geographic regions of interest. The discussion focuses on how these volumes were developed for 2000 and 2008, and then describes how the estimates for other years were produced. This section also describes diesel fuel supply volumes for 2008, which are used in the economic assessment.

Of course, only the amount of high-sulfur fuel used by land-based nonroad engines, locomotives, and marine vessels will be directly affected by today's proposal. In this analysis, the basic approach to estimating this fuel volume is to: 1) find the total diesel fuel demand in each category, 2) determine the respective amount of this fuel which already meets the highway fuel standards, and 3) subtract the low-sulfur volume from the total diesel fuel demand to yield the volume of high-sulfur diesel in the category.

Estimating diesel fuel consumption for the engine categories covered by the proposal also requires a basic understanding of the fueling practices for non-highway equipment. Generally, these equipment types are capable of using either high-sulfur diesel fuel or low-sulfur fuel that complies with the EPA highway diesel sulfur regulations. This latter fuel type may be used in non-highway applications for a variety of reasons. First, some equipment may be refueled at service stations where only low-sulfur, highway compliant fuel is available. Second, high-sulfur fuel may not be available due to limitations in the distribution or storage systems in some areas or during certain times of the year. Third, operators may choose to use low-sulfur diesel fuel based on some real or perceived benefit such as improved engine durability.

The estimates of diesel fuel volumes used in this analysis are principally based on the *Fuel Oil and Kerosene Sales 2000* (FOKS) report, which is produced by the Energy Information Administration (EIA).[1] This report represents the most detailed, comprehensive distillate fuel demand study available. The report contains estimates of distillate fuel sales for highway vehicles and 10 non-highway end uses. Unfortunately, the values reported in FOKS for the non-highway categories can not be used directly in this analysis, because it does not always report fuel volumes into the specific equipment types or diesel fuel grades that will be affected by the proposed rules.

As explained in detail in the next section, EPA in consultation with EIA identified six of the broadly reported categories in the EIA FOKS report as being relevant to this analysis. In addition, EPA found that EIA's railroad category contained distillate fuel used in both land-based nonroad engines, e.g., rail maintenance equipment and locomotives. Finally, EPA identified

EIA's vessel bunkering category as containing both recreational and commercial distillate fuel. The categories and end uses of interest from the EIA FOKS report are generally shown in Table 7.1-1.

Table 7.1-1
Application of EIA FOKS End Use Categories to EPA Off-Highway Categories

FOKS Category	EPA Proposal Categories		
	Land-Based Nonroad	Locomotives	Marine
Farm	X		
Other Off-Highway			
Construction	X		
Other	X		
Industrial	X		
Commercial	X		
Oil Company	X		
Military	X		
Railroad	X	X	
Vessel Bunkering (Marine)			X

Each of these topics is discussed in detail in the remainder of this section, along with the resulting estimates of high-sulfur diesel fuel that would be affected by the proposed rules.

7.1.2 Diesel Fuel Demand by PADD for 2000

High-sulfur diesel fuel is calculated by subtracting the low-sulfur diesel fuel demand from the total diesel fuel demand in the respective category. A common element in determining the volume of low-sulfur fuel is the amount, or percentage of low-sulfur, highway compliant diesel fuel that is spilled over into each of the non-highway end-use categories. Therefore, this section begins by identifying the amount of spillover for the various end uses of interest, and progresses to applying that information to estimate the volume of high-sulfur diesel fuel in each of the end-use categories.

7.1.2.1 Highway Diesel Fuel Volumes and Highway Spillover

Spillover is defined as the total volume of low-sulfur, highway compliant fuel supplied into the U.S. minus the volume of this fuel that is consumed (i.e., demand) by highway vehicles. The of volume of highway compliant fuel supplied to each PADD is provided in the Petroleum Supply Annual 2000, which is published by the Energy Information Agency.[2] The values from that report have been converted from barrels to gallons using a conversion factor of 42 gallons per barrel. The volume of highway fuel demand is provided in the EIA FOKS report.

Table 7.1-2 shows the spillover volumes in each of the five PADDs based on the above information.

Now that the total volume of low-sulfur diesel spillover is known, the next step in determining the low-sulfur spillover percentage is to find the total volume of diesel fuel consumed by all non-highway end-uses. The EIA FOKS report provides distillate sales numbers for the various off-highway end-use categories that could contain spillover fuel. Some of the distillate fuel grade categories contained in the report are quite broad in scope, making it difficult to accurately determine only the fuel volumes that are clearly interchangeable with the diesel fuel grades affected by the proposed rules. For example, certain end-use categories report distillate fuel oil or total distillate. These specifications may contain incompatible fuel types such as No. 4 fuel oil that is used in commercial burner applications. When more specific fuel grade information was unavailable, the volumes for these broader specifications are used to determine the total “potential” volume of non-highway fuel consumption. Fortunately, the volumes of these broad specification distillate fuels are relatively small compared to the total volumes of better defined diesel fuel grades. A detailed table showing how the potential non-highway diesel fuel volumes were determined is shown in Appendix 7A. The relevant fuel demand volumes are summarized in Table 7.1-3.

Table 7.1-2
Highway Diesel Fuel Spillover Volumes by PADD (million gallons)

Highway Diesel Category	1	2	3	4	5	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Supply	11,257	12,939	6,947	2,213	5,892	NA	2,633	NA	NA
Demand	10,228	11,141	5,644	1,475	4,643	NA	2,633	NA	NA
Spillover	1,029	1,799	1,303	738	1,250	NA	0	NA	NA

NA = Spillover volume is not used to determine the spillover percentages for these areas as explained later in Section 7.1.2.1.

Table 7.1-3
Potential Non-Highway Diesel Fuel Demand by PADD (million gallons)

End Use	PADD								
	1	2	3	4	5	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Residential	5,399	629	1	39	137	82	7	48	0
Commercial	1,944	567	347	13	213	97	87	26	3
Industrial	617	598	418	241	236	176	45	14	1
Oil Company	19	42	561	29	34	2	6	26	0
Farm	433	1,612	552	221	351	89	254	0	8
Electric Utility	305	134	195	9	151	17	8	36	90
Railroad	500	1,233	686	345	307	114	189	4	0
Marine	490	301	1,033	0	256	62	101	80	13
Military	70	36	9	4	113	89	7	6	11
Construction	511	549	394	150	295	91	194	7	3
Other	159	59	123	30	60	31	22	7	0
Total	10,447	5,760	4,319	1,171	2,153	849	921	254	129

The low-sulfur spillover percentages for the PADDs are calculated by dividing the total spillover volume in each PADD by the respective total potential non-highway demand volume. We use the demand volumes for all non-highway categories for this calculation, in the absence of information indicating that spillover fuel is used differentially in any non-highway end-use categories. This implicitly assumes that each spillover gallon has an equal chance of being sold for use in any non-highway application within each PADD.[A] The resulting low-sulfur spillover fractions for each of the five PADDs are shown in Table 7.1-4.

Table 7.1-4
Highway Diesel Fuel Spillover Percentages by PADD

Diesel Fuel Category	PADD I	PADD II	PADD III	PADD IV	PADD V
Highway Spillover (million gallons)	1,029	1,799	1,303	738	1,250
Potential Off-Highway (million gallons)	10,447	5,760	4,319	1,171	2,153
Spillover (%)	10	31	30	63	58

For PADD 5, it was necessary to develop separate refining regions within PADD 5 for the refinery cost analysis. For this reason, separate spillover percentages were estimated for these separate PADD 5 subregions. This was accomplished by first estimating the spillover percentages of states which are known to have specific spillover characteristics. The State of California already regulates the sulfur content of both the highway and nonroad diesel fuel pools to 500 ppm, thus very little of the diesel fuel is currently unregulated by the State. The tendency is that as more of the fuel pool is regulated, the higher the percentage of spillover into the non-highway diesel fuel pool as the distribution system has little tolerance for small volumes of high sulfur fuels. This was confirmed by talking to a staff member within California’s fuel regulatory division of the Air Resources Board. Based on this conversation, California’s spillover fraction was estimated to be 100 percent. At the other end of the spectrum, Alaska’s highway volume is much smaller than the non-highway volume, thus, very little spillover is expected. Using PADD 1 as a guide, which has about 10 percent spillover and a higher ratio of highway to non-highway diesel fuel, the spillover for Alaska was estimated to be half that of PADD 1, or 5 percent. The spillover for Hawaii and the rest of PADD 5 (Washington, Oregon, Nevada and Arizona) was back-calculated from volumes from these various states, their estimated spillover volumes and the overall spillover percentage of the PADD which is 58 percent. The spillover percent for Hawaii and the rest of PADD 5 was estimated to be 24 percent. The spillover percentages for each of the geographic areas in PADD 5 are shown in Table 7.1-5.

[A] Different national average estimates for spillover by non-highway end use still result due to differences in spillover percentages and fuel volumes among the non-highway applications between the PADDs.

* Different national average estimates for spillover by non-highway end use still result due to differences in spillover percentages and fuel volumes among the non-highway applications between the PADDS.

Table 7.1-5
Highway Diesel Fuel Spillover Percentages for PADD 5 Subregions

	PADD V AZ, NV, OR, WA	PADD V CA	PADD V AK	PADD V HI
Spillover (%)	24	100	5	24

The spillover percentages for PADDs 1-4 and the various subregions for PADD 5 are used in the following sections to estimate the volume of high-sulfur diesel fuel which would be affected by the proposed rules.

7.1.2.2 Land-Based Nonroad Fuel Volumes

As previously mentioned, the primary information source underlying our assessment of nonroad fuel volumes is the *Fuel Oil and Kerosene Sales* Report, published annually by the Energy Information Administration (EIA).[1] The report presents results of a national statistical survey of approximately 4,700 fuel suppliers, including refiners and large companies who sell distillate fuels for end use (rather than resale). The sample design involves classification of fuel suppliers based on sales volume (stratification), with subsamples in individual classes (strata) optimized to improve sample precision. Distillate fuels surveyed that are relevant to this analysis include diesel and heating oils in grades No. 1, No. 2 and No. 4, kerosene and jet fuel. The survey requests respondents to report estimates of fuel sold for eleven “end uses,” that correspond to broad economic sectors, such as “Industrial,” “Construction” and “Farm,” as described below. (See Table 7.1-6).

Before publication, EIA takes measures to quality-assure survey results. Automated and manual procedures serve to identify missing values, potential misreporting, and evaluate “outlier” values. Diesel consumption for the on-highway end use is represented by estimates published annually by the Federal Highway Administration (FHWA).[3] EIA uses the FHWA data because it is their perspective that EIA’s sampling technique gives inadequate coverage of truck stops. Finally, they perform an adjustment or “post-stratification,” to bring total survey results into agreement with total annual supply as reported in the *Petroleum Supply Annual*.[2] For this step, “supply” refers to “product-supplied” to the end-use market, calculated as domestic production plus imports less exports and stock changes, as calculated for each Petroleum Administration for Defense District (PADD). The adjustment is calculated at the PADD level, and applied uniformly to each state and end-use within each PADD.

The EIA FOKS report estimates volumes of distillate sold into end-uses or economic sectors. It does not directly represent fuel consumption, or attempt to determine how fuel is used after it is sold. Thus, sales estimates encompass all potential uses, including on-highway mobile sources, non-road mobile sources, and stationary sources such as heating, cooling, crop drying and power generation. In deriving an estimate of total fuel consumption for nonroad engines, our basic approach is to estimate a fraction of total sales in each end use that represents nonroad fuel consumption. With the exception of the railroad and on-highway end uses, the resulting fractions directly follow guidance from EIA staff.

We derived the nonroad fraction in each end use in two steps. Beginning with total fuel volumes for a given fuel grade or grades, we estimate a proportion representing diesel fuel (as opposed to heating oil), and of the diesel fuel portion, we estimate a second fraction assumed to represent nonroad use. We describe nonroad diesel fuel consumption as estimated for each end use category below.

Farm. For this end use, two fuel grades are reported, “diesel” and “distillate.” We assume that 100% of the diesel represents nonroad use, and 0% of the distillate, which represents other uses, such as heating and crop drying.

Construction/Other Off-Highway(Logging). For the construction and logging/other-non-highway end uses, we assume that 95% of total sales is diesel fuel, and that 100% of the diesel represents nonroad use.

Industrial. This end use is essentially equivalent to the manufacturing sector, and differs from most others in that EIA reports sales for five individual fuel grades, which simplifies estimation of nonroad diesel consumption. At the outset, we assume that sales of No. 2 fuel oil and No. 4 distillate include no diesel fuel. These grades represent other uses in this category, such as space heating, meaning that none of the fuel in these categories represents nonroad use. Conversely, for No. 2 diesel (low and high sulfur), we assume that 100% of sales is diesel fuel, and 100% of the diesel represents nonroad use. For the remaining category, No. 1 distillate, diesel and fuel oil are not distinguished. Following guidance from EIA staff, we have estimated that 40% of No. 1 distillate sales represent diesel fuel, that 100% of this diesel represents nonroad use, and that the remainder represents No. 1 fuel oil used in other applications, such as space heating.

Commercial. This end use is broadly equivalent to the service sector. As with the industrial end use, distillate sales are also reported by fuel grade. However, the commercial and industrial end uses differ in that the commercial category includes sales for on-highway use. Distillate sales for use in motor vehicles include fuel supplied to school-bus and government fleets (local, state and federal). These sales are classified as “commercial” sales because they are exempt from fuel taxes, as is fuel for nonroad use in most jurisdictions. As in the industrial end use, we assume that none of the No. 2 fuel oil or No. 4 distillate represents nonroad use of diesel fuel. In addition, to account for the on-highway fuel consumption in this end use, we assume that none of the low-sulfur No. 2 diesel represents nonroad use. As in industrial, we assign 100% of the high-sulfur No. 2 diesel to nonroad use. After consultation with EIA staff, we have estimated that 40% of the No. 1 distillate is diesel fuel, and that 50% of this diesel represents nonroad use.

For most of the remaining end uses, individual fuel grades are not distinguished, necessitating broader assumptions in estimation of nonroad fuel use.

Oil Company. Sales for this end use include fuel purchased for drilling and refinery operations. We assume that 50% of the reported distillate is diesel fuel, and assign 100% of the diesel to operation of nonroad equipment. We assume that the remainder represents other uses such as underground injection under pressure to fracture rock.

Military. For the military end use, fuel sales are reported for diesel and distillate. We assume that 85% of the diesel represents use in 'non-tactical' nonroad equipment, and that 0% of the distillate represents nonroad use. We exclude some fuel because the NONROAD model does not attempt to represent fuel use or emissions from 'tactical' military equipment, such as tanks and personnel carriers because they are not covered by EPA emission standards.

Railroad. Again, we assume that the vast majority of fuel sales in the railroad end use represents locomotive operation, however, based on guidance from a major railroad, we assume that a small fraction of reported sales represent operation of nonroad equipment used by railroads. Accordingly, we assign 1% of the railroad fuel sales to nonroad use, which corresponds to "Railway Maintenance" equipment as represented in the NONROAD model.

In three of the remaining end uses, *Electric Utility*, *Vessel Bunkering* and *Residential*, we assign no fuel to nonroad use.

On-Highway. As the name implies, this end use represents sales for use in motor vehicles on roads and highways, and is represented in the survey by the volume reported by FHWA.[3] Many organizations own mixed fleets and purchase both highway and non-road diesel, for which reason it is plausible to assume that some fraction of the fuel attributed by FHWA to on-highway use is actually used in nonroad engines. Because owners can legally use undyed low-sulfur diesel in nonroad equipment, convenience or economy may encourage owners who purchase undyed diesel to use it in nonroad equipment. Additionally, some owners might find it expedient or necessary to purchase at least some of their diesel in commercial outlets such as gas stations, where dyed "offroad" diesel is less available.

However, to reassign a fraction of the on-highway fuel to nonroad use, it is not sufficient simply to postulate that low-sulfur undyed diesel is used in nonroad engines. Additional constraints must be met to ensure that the EIA survey has not included the fuel in another end-use, and that FHWA has not accounted for the fuel by subtracting it from the on-highway total. For purposes of this study, we believe that four conditions must apply to justify a presumption that fuel sales assigned to on-highway use would have been used in nonroad engines: (1) The fuel sales were taxed, i.e., sales of undyed "low-sulfur highway diesel," (2) The buyer does not claim a tax credit or refund on the fuel sale(s), (3) The buyer uses the fuel in nonroad equipment, and (4) The EIA survey has not already accounted for the fuel.

The first condition is necessary because FHWA estimates on-highway fuel on the basis of fuel tax receipts reported by the states. In general, sales of undyed diesel are subject to state and federal sales and use taxes; however, the purchaser is eligible for a tax refund or credit in most jurisdictions, if the fuel is used in offroad equipment. To account for this possibility, FHWA subtracts tax refunds from total receipts, which should effectively remove undyed fuel purchased for use in nonroad equipment from the on-highway total. However, it is probable that only a fraction of owners who are eligible actually take advantage of fuel tax refunds or credits, because they are unaware that the option is available or because they find the process inconvenient. Thus, if the purchaser forgoes applying for a refund or credit, FHWA leaves the fuel in the on-highway total (the second condition above), and if the fuel is actually used in nonroad equipment (the third condition above), FHWA also misclassifies it as on-highway consumption.

To reclassify such fuel as nonroad consumption, it is also necessary to be confident that the EIA survey has not effectively assigned it to another end use (the fourth condition above). During quality-assurance, EIA attempts to identify and remove distillate sales intended “primarily for on-highway use” Fractions of such sales used in nonroad engines would thus not be reflected in estimates of distillate sales. Also, fuel purchased at truck stops or gas stations and subsequently used in nonroad equipment would not appear in survey results, because the survey does not attempt to represent sales from these retail outlets.

An example scenario meeting all four conditions stated above would represent sales of undyed diesel at retail outlets, for which the purchaser claims no tax credit or refund, and uses the fuel in nonroad equipment. We assume that such a scenario is not uncommon in the construction or commercial end uses, in which operations can be decentralized, dispersed or remote, and operators numerous and highly mobile, refueling when and where convenient. Such a situation is especially likely for the growing fleet of diesel rental equipment where available refueling sites are likely to be highway service stations and where volumes may not warrant seeking tax refunds.

The Northeast States for Coordinated Air Use Management (NESCAUM) recently conducted a survey of diesel fuel use in construction equipment in New England, under a grant funded by EPA. The survey was designed to develop methods to estimate emission inventories for construction equipment. The study area included two counties, one in Massachusetts and one in Pennsylvania. Equipment owners in selected sectors were targeted, including construction, equipment rental, wholesale trade, and government (local highway departments). Surveyors administered a questionnaire requesting information about fuel purchases and associated tax-credits. Owners reported quantities and proportions of high-sulfur (dyed) and low-sulfur (undyed) diesel fuel purchased over the previous year. Owners who reported purchases of undyed diesel fuel for use in construction equipment were also requested to indicate whether they applied for tax credits for which they would be eligible under state or federal law.

Based on EPA’s analysis of the survey results, approximately 20% of all diesel fuel purchased for use “in construction” was undyed diesel for which the purchaser had not applied for a tax refund. For purposes of deriving a protective estimate, it was assumed that 50% of the un-refunded fuel was purchased at gas stations or truck stops, amounting to 10% of total diesel purchased for use "in construction equipment." In the context of the scenario described above, the implication is that 10% of the total nonroad fuel consumption in the construction and commercial end uses (F_{TOTAL}) is undyed diesel misclassified as on-highway use (F_{FHWA}), or

$$F_{\mathrm{FHWA}} = 0.1F_{TOTAL}$$

At the same time, the nonroad fuel consumption in these end uses captured by the FOKS survey (F_{FOKS}) comprises the remaining 90% of the total, or

$$F_{\mathrm{FOKS}} = 0.9\,F_{\mathrm{TOTAL}}$$

These two relationships allow us to estimate the misclassified diesel fuel in terms of nonroad fuel consumption estimated from the FOKS survey

$$F_{\mathrm{FHWA}} = 0.1\left(\frac{F_{\mathrm{FOKS}}}{0.9}\right) \quad = \quad \left(\frac{0.1}{0.9}\right)F_{\mathrm{FOKS}} \quad = \quad 0.11F_{\mathrm{FOKS}}$$

meaning that F_{FHWA} can be estimated as ~$0.1F_{\mathrm{FOKS}}$.

We estimated the misclassified highway volume (F_{FHWA}) at the national level and individually for each PADD, using FOKS-derived estimates of nonroad diesel consumption in the construction and commercial end uses for the nation and each PADD, respectively. Summing across the nation, this estimate represents 230 million gallons or approximately 0.7% of the on-highway total.

Table 7.1-6 presents national land-based nonroad fuel consumption for calendar year 2000, by end use. At the national level, the table shows estimates of total sales in each end use, plus fractions representing diesel fuel and nonroad consumption, and resulting fuel volumes representing nonroad consumption.

We derived fuel consumption estimates for each PADD by applying the same distillate and diesel fractions developed above to fuel sales for each PADD. To meet requirements for the economic analysis, the states of California, Hawaii and Alaska are presented individually, with the remaining states in PADD 5 treated as an aggregate. Tables 7.1-7 and 7.1-8 present fuel sales and estimated nonroad fuel consumption for each PADD, with PADD 5 subdivided as described.

Table 7.1-6
Land-Based Nonroad Distillate Use, National Estimates, Calendar Year 2000

End Use	Fuel Grade	Distillate (M gal)	Diesel (%)	Diesel (M gal)	Nonroad (%)	Nonroad (M gal)
Farm	diesel	3,080	100	3,080	100	3,080
	distillate	89	0	0	0	0
Construction	distillate	1,900	95	1,805	100	1,805
Other/(Logging)	distillate	431	95	409	100	409
Industrial	No. 2 fuel oil	357	0	0	0	0
	No. 4 distillate	39	0	0	0	0
	No. 1 distillate	54	40	22	100	22
	No. 2 low-S diesel	810	100	810	100	810
	No. 2 high-S diesel	889	100	889	100	889
Commercial	No. 2 fuel oil	1,576	0	0	0	0
	No. 4 distillate	198	0	0	0	0
	No. 1 distillate	64	40	25	50	13
	No. 2 low-S diesel	1,061	100	1,061	0	0
	No. 2 high-S diesel	475	100	475	100	475
Oil Company	distillate	685	50	342	100	342
Military	diesel	180	100	180	85	153
	distillate	54	0	0	0	0
Electric Utility	distillate	793	100	793	0	0
Railroad	distillate	3,071	95	2,917	1.0	29
Vessel Bunkering	distillate	2,081	90	1,873	0	0
On-Highway	diesel	33,130	100	33,130	0.7	229
Residential	No. 2 fuel oil	6,086	0	0	0	0
	No. 1 distillate	118	0	0	0	0
Total		57,217		47,800		8,254

Table 7.1-7
Distillate Fuel Sales by PADD, Calendar Year 2000 (million gallons)

End Use	Fuel Grade	PADD							
		1	2	3	4	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Farm	diesel	389	1,572	549	219	90	254	0.03	8
	distillate	44	40	3	1	0.08	0	0.001	0
Construction	distillate	511	549	394	150	91	194	7	3
Other/(Logging)	distillate	160	59	123	30	31	22	7	0.04
Industrial	No. 2 fuel oil	219	111	4	8	11	0.3	4	0.05
	No. 4 distillate	33	3	2	2	1	0	0	0
	No. 1 distillate	1	26	3	13	1	0	10	0
	No. 2 low-S diesel	116	176	193	202	79	43	0.02	1
	No. 2 high-S diesel	281	285	218	18	74	2	10	0.6
Commercial	No. 2 fuel oil	1,304	102	141	7	5	3	12	0.05
	No. 4 distillate	197	0.7	0	0	0.02	0	0.02	0
	No. 1 distillate	3	36	0.9	11	3	0.4	10	0
	No. 2 low-S diesel	418	276	146	69	66	79	4	3
	No. 2 high-S diesel	219	153	58	16	15	5	6	3
Oil Company	distillate	19	42	561	29	1	6	26	0.05
Military	diesel	41	15	9	2	87	7	6	11
	distillate	29	21	11	2	2	0	0.05	0
Electric Utility	distillate	304	134	195	8	106	8	36	0.9
Railroad	distillate	500	1,233	686	345	114	189	4	0
Vessel Bunkering	distillate	490	301	1,033	0.2	61	101	80	13
On-Highway	diesel	10,228	11,141	5.644	1,475	1,885	2,633	91	34
Residential	No. 2 fuel oil	5,391	557	1	30	76	7	25	0.009
	No. 1 distillate	8	72	0.1	9	6	0.2	23	0
Total		20,906	16,904	9.976	2,647	2,806	3,553	361	78

Table 7.1-8
Land-Based Nonroad Diesel Consumption for the Nation and by PADD, 2000 (million gallons)

End Use	Fuel Grade	Nation	PADD							
			1	2	3	4	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Farm	diesel	3,080	389	1,572	549	219	89	254	0.03	8
	distillate	0	0	0	0	0	0	0	0	0
Construction	distillate	1,805	485	522	375	143	86	184	6	3
Other/(Logging)	distillate	409	151	56	116	29	30	21	6	0.04
Industrial	No. 2 fuel oil	0	0	0	0	0	0	0	0	0
	No. 4 distillate	0	0	0	0	0	0	0	0	0
	No. 1 distillate	22	0.5	10	1	5	0.5	0	4	0
	No. 2 low-S diesel	810	116	176	193	202	79	43	0.02	1
	No. 2 high-S diesel	889	281	285	218	18	74	2	10	0.6
Commercial	No. 2 fuel oil	0	0	0	0	0	0	0	0	0
	No. 4 distillate	0	0	0	0	0	0	0	0	0
	No. 1 distillate	13	0.5	7	0.2	2	0.5	0.1	2	0
	No. 2 low-S diesel	0	0	0	0	0	0	0	0	0
	No. 2 high-S diesel	475	219	153	58	16	15	5	6	3
Oil Company	distillate	342	10	21	280	15	0.7	3	13	0.02
Military	diesel	153	35	13	8	2	74	6	5	9
	distillate	0	0	0	0	0	0	0	0	0
Electric Utility	distillate	0	0	0	0	0	0	0	0	0
Railroad	distillate	29	5	12	7	3	1	2	0.04	0
On-Highway	diesel	229	71	68	43	16	10	19	1	0.6
Total		8,254	1,762	2,895	1,849	669	461	539	54	26

The high-sulfur diesel fuel volumes are estimated by applying the highway spillover percentages to the results shown in Tables 7.1-4 and 7.1-5. Specifically, the spillover percentage is applied to the volume of diesel fuel remaining after the reclassified highway volume (i.e., highway fuel actually used in nonroad engines) is subtracted from the total land-based nonroad engine volume. This is done because the spillover fraction was developed from the total highway demand before the transfer was made. Table 7.1-9 shows the derivation of the high-sulfur diesel fuel volume for land-based nonroad engines.

Table 7.1-9
Land-Based High-Sulfur Diesel Fuel Demand by PADD, 2000 (million gal)

	PADD							
Diesel Fuel Category	1	2	3	4	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Total Land-Based	1,762	2,895	1,849	669	461	539	54	26
Low-Sulfur Hwy Transfer	71	68	43	16	10	19	1	1
Total Less Hwy Transfer	1,691	2,827	1,806	653	451	520	53	25
Hwy Spillover Percentage (%)	10	31	30	63	24	100	5	24
Land-Based Low Sulfur	168	882	545	410	107	520	3	6
Land-Based High Sulfur	1,523	1,945	1,261	243	344	0	50	19

7.1.2.3 Locomotive Diesel Fuel Demand

The estimates of diesel fuel demand for locomotives are taken from the information presented in Section 7.1.2.2. In summary, the locomotive estimates were developed by taking the railroad distillate fuel values directly from the EIA FOKS report for the geographic areas of interest, and multiplying them by 0.95, which is the fraction of distillate fuel that is assumed to be diesel grade. This results in estimates of the diesel fuel demand for railroads. To find only the volume of diesel fuel used by locomotives, the fraction of diesel fuel that is assumed to be used by rail maintenance (i.e., 0.01) is subtracted from the diesel railroad volumes. The estimates of high-sulfur diesel are determined by applying the highway spillover percentages to the total locomotive fuel volumes.

The locomotive fuel demand estimates for 2000 are shown in Table 7.1-10 for the geographic areas of interest.

Table 7.1-10
Locomotive High-Sulfur Diesel Fuel Demand by PAAD, 2000 (million gallons)

	PADD							
Diesel Fuel Category	1	2	3	4	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Total Locomotive	470	1,160	646	324	107	178	4	0
Hwy Spillover Percentage (%)	10	31	30	63	24	100	5	24
Locomotive Low Sulfur	47	362	195	204	25	178	0	0
Locomotive High Sulfur	423	798	451	120	82	0	4	0

7.1.2.4 Marine Diesel Fuel Demand

The estimates of diesel fuel demand for marine vessels were developed base on guidance from EIA staff. Specifically, the demand volumes are estimated by taking the vessel distillate values directly from the EIA FOKS report and multiplying it by 0.90, which is the fraction of distillate fuel sales that is assumed to represent diesel fuel for that category. The estimates of high-sulfur diesel are determined by applying the highway spillover percentages to the resulting total marine fuel volumes.

The marine fuel demand estimates for 2000 are shown in Table 7.1-11 for the geographic areas of interest.

Table 7.1-11
Marine High-Sulfur Diesel Fuel Demand by PAAD, 2000 (million gallons)

Diesel Fuel Category	PADD							
	1	2	3	4	5 (except CA, HI, AK)	5 CA	5 AK	5 HI
Total Marine	441	271	930	0	55	91	72	12
Hwy Spillover Percentage (%)	10	31	30	63	24	100	5	24
Marine Low Sulfur	47	36,285	281	0	13	91	4	3
Marine High Sulfur	397	7,186	649	0	42	0	68	9

7.1.2.5 Remaining Non-Highway Diesel Fuel Demand

It is also necessary to estimate diesel fuel demand volumes for the remaining non-highway end uses that may use diesel fuel in order to complete the economic analysis. By definition, this category includes any application other than land-based nonroad engines, locomotives, or marine vessels.

The demand for diesel fuel in this broad category is found in three steps. First, the overall volumes of fuel consumed by all non-highway end-uses is determined from the EIA FOKS report. These demand volumes were developed for the geographic areas of interest as presented in Section 7.1.2.1, Table 7.1-3. Second, the demand volumes are adjusted to include the volume of fuel reclassified from the highway vehicle category to the land-based nonroad engine category. These volumes were derived in Section 7.1.2.2, Table 7.1-8. Third, and finally, diesel fuel demands for remaining non-highway end uses are calculated by subtracting the combined volumes for land-based nonroad engines, locomotives, and marine vessel (as previously determined in Sections 7.1.2.2 through 7.1.2.4) from the adjusted diesel demand for all non-highway end uses. The estimates of high-sulfur diesel are then found by applying the highway spillover percentages to these other non-highway demand volumes. The results are shown in Table 7.1-12.

Table 7.1-12
Other Off-Highway High-Sulfur Diesel Fuel Demand by PADD, 2000 (million gallons)

	PADD							
Diesel Fuel Category	1	2	3	4	5 AZ, NV, OR, WA	5 CA	5 AK	5 HI
Potential Off-Highway	10,447	5,760	4,319	1,171	849	921	254	129
Highway Transfer	71	68	43	16	10	19	1	1
Adjusted Off-Highway	10,518	5,828	4,362	1,187	859	940	255	130
Land-Based Nonroad, Locomotive, and Marine	2673	4326	3425	993	623	808	130	38
Other Off-Highway	7,845	1,502	937	194	307	131	141	7
Hwy Spillover Percentage (%)	10	31	30	63	24	100	5	24
Other Off-Highway Low Sulfur	781	469	283	122	73	131	7	2
Other Off-Highway High Sulfur	7,064	1,034	654	72	234	0	134	5

7.1.2.6 Summary of Diesel Fuel Demand for 2000

Table 7.1-13 summarizes the diesel fuel demand estimates for each of the geographic areas of interest for 2000 based on the information in the preceding sections. In this table, the low-sulfur demand volumes for land-based nonroad engines are found by applying the highway spillover percentages to the total volumes for this category minus the reclassified highway gallons. The reclassified highway spillover gallons are then added to these results to produce the total low-sulfur volumes for land-based nonroad engines. Totals for the U.S. and the U.S. minus California are also shown for completeness.

Table 7.1-13
Summary of Diesel Fuel Demand for 2000 (million gallons)

Category	Fuel Type	PADD									
		1	2	3	4	5 AZ, NV, OR, WA	AK	HI	CA	U.S.	U.S. - CA
Revised Highway	total	10,157	11,074	5,601	1,459	1,875	90	33	2,614	32,902	30,288
	high S	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Land-Based Nonroad	total	1,762	2,895	1,849	669	461	54	26	539	8,255	7,716
	low S	239	950	588	426	117	4	7	539	2,871	2,332
	high S	1,523	1,945	1,261	243	344	50	19	0	5,384	5,384
Locomotive	total	470	1,160	646	324	107	4	0	178	2,889	2,711
	low S	47	362	195	204	25	0	0	178	1,011	833
	high S	423	798	451	120	82	4	0	0	1,878	1,878
Marine	total	441	271	930	0	55	72	12	91	1,872	1,781
	low S	44	85	281	0	13	4	3	91	520	429
	high S	397	186	649	0	42	68	9	0	1,352	1,352
Subtotal (NR, Loc, Marine)	total	2,673	4,326	3,425	993	623	130	38	808	13,016	12,208
	low S	330	1,397	1,064	630	155	7	10	808	4,402	3,594
	high S	2,343	2,929	2,361	363	468	123	28	0	8,614	8,614
Other Non-Highway	total	7,845	1,502	937	194	307	141	7	131	11,065	10,934
	low S	781	469	283	122	73	7	2	131	1,868	1,737
	high S	7,064	1,034	654	72	234	134	5	0	9,197	9,197
TOTAL	total	20,675	16,902	9,963	2,646	2,805	361	78	3,553	56,983	53,430
	low S	11,269	12,939	6,948	2,211	2,103	105	44	3,553	39,171	35,618
	high S	9,406	3,963	3,015	435	702	257	34	0	17,812	17,812

7.1.3 Diesel Fuel Demand by PADD for 2008

Diesel fuel demand in 2008 is projected for each end use category by applying various growth factors to the 2000 diesel fuel demand volumes shown in Table 7.1-13. This section shows how the growth factors were determined and applied to each end-use category. Finally, the low-sulfur diesel fuel estimates for 2008 are divided into separate volumes of 15 ppm and 500 ppm sulfur concentrations (i.e., highway diesel fuel) in order to facilitate the air quality analysis.

7.1.3.1 2000-2008 Growth Factors

The growth factors for highway diesel fuel, locomotives, and other non-highway end uses were developed from the *Annual Energy Outlook 2002* (AEO2002) report, which is published by the Energy Information Administration.[4] The growth factor for land-based nonroad engines was taken from estimates of diesel fuel consumption from the draft NONROAD2002 model. The factor for marine diesel fuel was developed from information contained in the 1999 Final Regulatory Impact Analysis for the Marine Diesel Emission Standards, which was published by EPA.[5] Each of the growth factors and their respective sources are shown in Table 7.1-14. The derivation of the composite growth factor that was used for the other non-highway end use category is shown in Table 7.1-15.

Table 7.1-14
2000-2008 Growth Factors by End-Use Category

End Use	2000-2008 Multiplicative Growth Factor	% Simple Annual Growth Rate	Source/Comments
Highway	1.238	2.98	AEO2002, Table 7, Energy Use by Mode, Freight Trucks (over 10,000 lbs. GVWR)
Land-Based Nonroad	1.229	2.87	Calculated from 2000 and 2008 Draft NONROAD2002 Model diesel fuel consumption outputs.
Locomotive	1.083	1.04	AEO 2002, Table 7, Energy Use by Mode, Railroad
Marine	1.090	1.13	Calculated from 2000 and 2008 CO emissions inventories (as a surrogate for fuel consumption) as reported in the Final Regulatory Impact Analysis, Control of Emissions for Marine Diesel Engines, 1999.
Other Non-Highway	1.074	0.93	See Table 7.1-15. Primarily diesel fuel and heating oil.

Table 7.1-15
2000-2008 Composite Growth Factor for Other Non-Highway End-Uses

End Use	Energy Consumption (Quadrillion BTU)	Fraction of Total	2000-2008 Multiplicative Growth Factor	Consumption Weighted Multiplicative Growth Factor	Source of Energy Consumption
Commercial	0.42	0.174	1.105	0.192	AEO2002, Table 2, Commercial, Distillate Fuel
Industrial	1.18	0.489	1.063	0.520	AEO2002, Table 2, Industrial, Distillate Fuel
Farm	0.528	0.219	1.039	0.227	AEO2002, Table 32, Agriculture, Distillate Fuel
Construction	0.285	0.118	1.138	0.134	AEO2002, Table 32, Construction, Distillate Fuel
Composite Average[a]				1.074	

[a] Growth in the residential heating oil end-use category was inadvertently excluded from the composite growth factor of the other non-highway category. This will be added for the final rulemaking.

The 2000-2008 average annual growth rate of 2.87 percent for land-based nonroad engines, presented in Table 7.1-14 above, is identical to that used in Chapter 3 for these engines. This compares with an annual growth rate of 0.97 percent that was developed using data from AEO2002 (See Appendix 7B.) The growth rates for locomotives and marine shown in Table 7.1-14 are the same as the values used in Chapter 3 for these engines.

7.1.3.2 Division of Low-Sulfur Diesel Fuel into 15 ppm and 500 ppm Volumes

As previously noted, the highway diesel fuel spillover volume is divided into 15 ppm and 500 ppm sulfur levels to facilitate the air quality analysis. The 15 ppm sulfur pool is projected to comprise 74 percent of the spillover volume, while 500 ppm sulfur pool is projected to comprise 26 percent of the spillover volume. The value is 74 percent 15 ppm diesel fuel because although 80 percent of each PADDs highway diesel fuel must be 15 ppm in 2006, highway diesel fuel produced by small refineries is allowed to be exempt from having to comply in 2006, and they comprise 5 percent of the national highway diesel fuel production volume. Then, the 75/25 relative volumes were adjusted to account for downgrading in the distribution system thus resulting in the 74 and 26 percent values. When this volume methodology was created, the highway plans for most of the small refiners were not known, so it was assumed that all of them would take the delay option. However, we now know that some are taking the gasoline for diesel fuel option which requires them to comply with the highway diesel fuel option in 2006, in return for a three year delay with the Tier 2 gasoline sulfur standard. These small refineries will therefore comply with the Highway Program sulfur requirements in 2006 and will make the percentage of highway diesel fuel complying to the 15 ppm cap standard in 2006 closer to 80 percent. This will be updated for the final rulemaking.

7.1.3.3 Summary of Diesel Fuel Demand for 2008

The diesel fuel demand estimates for 2008 are shown in Table 7.1-16.

Table 7.1-16
Summary of Diesel Fuel Demand by PADD for 2008 (million gallons)

Category	Fuel Type	PADD									
		1	2	3	4	5 AZ, NV, OR, WA	AK	HI	U.S. - CA	CA	U.S.
Revised Highway	total	12,575	13,710	6,934	1,806	2,321	111	41	37,499	3,236	40,735
	15 ppm diesel	9,324	10,165	5,141	1,339	1,721	83	30	27,804	3,236	31,040
	500 ppm diesel	3,251	3,544	1,793	467	600	29	11	9,695	0	9,695
	high S	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Land-Based Nonroad	total	2,166	3,559	2,273	822	567	66	32	9,486	663	10,149
	15 ppm diesel	219	866	536	389	106	3	6	2,125	662	2,788
	500 ppm diesel	77	302	187	135	37	1	2	741	0	741
	high S	1,872	2,391	1,550	298	423	62	23	6,620	0	6,620
Locomotive	total	509	1,256	700	351	116	4	0	2,936	193	3,129
	15 ppm diesel	38	291	157	163	20	0	0	669	193	862
	500 ppm diesel	13	101	55	57	7	0	0	233	0	233
	high S	458	864	488	130	88	4	0	2,034	0	2,034
Marine	total	481	295	1,014	0	60	78	13	1,941	99	2,040
	15 ppm diesel	35	68	227	0	11	3	2	347	99	446
	500 ppm diesel	12	24	79	0	4	1	1	121	0	121
	high S	433	203	708	0	46	75	10	1,474	0	1,474
Subtotal (NR, Loc, Marine)	total	3,156	5,111	3,987	1,173	743	149	45	14,364	955	15,318
	15 ppm diesel	291	1,225	920	552	137	6	9	3,141	955	4,096
	500 ppm diesel	102	427	321	193	48	2	3	1,095	0	1,095
	high S	2,763	3,458	2,746	429	557	141	33	10,127	0	10,127
Other Off-Highway	total	8,425	1,614	1,007	209	330	151	8	11,743	141	11,884
	15 ppm diesel	622	373	225	97	58	6	1	1,383	141	1,524
	500 ppm diesel	217	130	79	34	20	2	0	482	0	482
	high S	7,586	1,110	703	78	252	144	6	9,878	0	9,878
TOTAL	total	24,157	20,434	11,927	3,188	3,394	412	93	63,605	4,332	67,937
	15 ppm diesel	10,238	11,764	6,287	1,988	1,917	95	40	32,328	4,332	36,660
	500 ppm diesel	3,570	4,102	2,192	693	669	33	14	11,272	0	11,272
	high S	10,349	4,569	3,448	506	809	284	39	20,005	0	20,005

7.1.4. Annual Diesel Fuel Demand (2000-2040) and Associated In-Use Sulfur Levels

The annual diesel fuel volumes and respective in-use sulfur concentrations for land-based nonroad engines, locomotives, and marine vessels are estimated in this section. The estimates of in-use diesel fuel sulfur levels are used in emissions inventory analysis. The diesel volumes are used in the economic analysis. Some of these volume estimates are also used in the emissions inventory analysis described in Chapter 3.

This section begins with a description of the methodology that is used to estimate the diesel demand volumes for 2000-2040. Then the basic inputs for determining the in-use sulfur concentration is discussed. Finally, the volumes and corresponding in-use sulfur levels for each year are presented.

7.1.4.1 Annual Diesel Demand Volume Estimates

Diesel fuel volume estimates by year and by geographic area (nationwide, 49-state without California, and 48-state without Alaska or Hawaii) and corresponding average sulfur levels by year were calculated from the 2008 fuel use estimates presented in Section 7.1.3. The resulting volumes and sulfur levels are presented below in Section 7.1.4.3. The demand estimates for each of the other years were determined by extrapolating the 2008 values according to the nationwide growth rates shown in Table 7.1-17 for land-based nonroad model equipment categories, locomotives, and marine (commercial and recreational). The sources for these growth rates are the same as described earlier in Table 7.1-14.

Although the growth rates in the two tables are consistent, they are not directly comparable. The values in Table 7.1-14 are expressed as simple annual growth (i.e., the percentage change from 2000-2008 divided by the number of years, in this case eight years). The values in Table 7.1-17 are expressed as a percentage change from the previous year, or year-to-year change.

Table 7.1-17
Nationwide Annual Growth Rates for Nonroad Diesel Fuel Use

Year	Nonroad	Locomotive	Marine
2000	—	—	—
2001	2.88	5.15	1.08
2002	2.80	-1.63	1.08
2003	2.72	1.74	1.08
2004	2.65	1.38	1.09
2005	2.58	1.38	1.09
2006	2.50	0.97	1.09
2007	2.44	0.97	1.10
2008	2.38	0.44	1.10
2009	2.32	0.69	1.10
2010	2.27	0.72	1.11
2011	2.23	1.70	1.11
2012	2.18	0.45	1.11
2013	2.14	0.27	1.12
2014	2.09	0.28	1.12
2015	2.05	0.45	1.12
2016	1.99	1.02	1.13
2017	1.95	0.57	1.13
2018	1.91	0.52	1.13
2019	1.88	0.56	1.14
2020	1.84	0.33	1.14
2021	1.81	0.89	1.15
2022	1.78	0.89	1.15
2023	1.75	0.89	1.16
2024	1.72	0.89	1.16
2025	1.69	0.89	1.16
2026	1.65	0.89	1.17
2027	1.62	0.89	1.17
2028	1.60	0.89	1.18
2029	1.57	0.89	1.18
2030	1.55	0.89	1.19
2031	1.52	0.89	1.19
2032	1.50	0.89	1.20
2033	1.48	0.89	1.20
2034	1.46	0.89	1.21
2035	1.44	0.89	1.21
2036	1.41	0.89	1.22
2037	1.40	0.89	1.23
2038	1.38	0.89	1.23
2039	1.36	0.89	1.24
2040	1.34	0.89	1.24

7.1.4.2 In-Use Diesel Sulfur Concentrations

Table 7.1-18 shows the diesel sulfur levels that were used in generating the national in-use average sulfur levels by year that are shown in Section 7.1.4.3.

Table 7.1-18
Factors Used to Calculate In-use Sulfur Levels

Parameter	Value
Average in-use sulfur level for fuel intended to be used in nonroad engines, prior to sulfur control	3400 ppm
Average in-use fuel sulfur level for any fuel designed to meet a standard of 500 ppm	340 ppm
Average in-use fuel sulfur level for fuel designed to meet California's diesel fuel specifications	120 ppm
Average in-use fuel sulfur level for any fuel designed to meet a standard of 15 ppm	11 ppm
Nonroad spillover: Percentage of fuel consumed by nonroad engines that is actually produced to meet highway fuel sulfur standards	34.9%
Locomotive and marine spillover: Percentage of fuel consumed by locomotives and marine vessels that is actually produced to meet highway fuel sulfur standards	32.4%

Each of the sulfur levels and spillover assumptions is further described below.

High-Sulfur Diesel Fuel. The national average in-use sulfur level of uncontrolled nonroad, locomotive, and marine diesel fuel is approximately 3400 ppm. This estimate is derived from 1996 through 2001 fuel survey data reported by the National Institute for Petroleum and Energy Research (NIPER) and TRW Petroleum Technologies (TRW).[6,7] These annual reports provide measured sulfur concentrations and respective fuel volumes for multiple samples in several geographic regions of the country. The information was used to estimate the national average in-use sulfur level as follows. First, the geographic regions were assigned to each of the five PADDs. Second, individual annual average sulfur levels in each PADD were calculated by weighting the respective sulfur content of each sample by its fuel volume (i.e., volume weighting). Third, an overall average sulfur level for each PADD was found by volume weighting the individual annual average sulfur concentrations. Fourth, the national average sulfur level was determined by volume weighting each PADD’s overall average sulfur concentration. The final results of this analysis are shown in Table 7.1-19. The details of the method are provided in a memo to the Docket entitled, “Derivation of the National Average In-use Sulfur Level of Uncontrolled Nonroad, Locomotive, and Marine Diesel Fuel”.

Table 7.1-19
In-Use Sulfur Concentrations for High-Sulfur Diesel Fuel

PADD	Year	Volume (million gallons)	Sulfur
1	1996	7,637,500	3,423
	1997	6,000,000	2,663
	1998	4,637,500	3,998
	1999	4,275,000	3,474
	2000	9,025,000	3,653
	2001	4,937,500	3,055
	Average	36,512,500	3,384
2	1996	2,825,000	3,600
	1997	2,775,000	2,740
	1998	1,275,000	1,818
	1999	2,912,500	1,717
	2000	10,412,500	2,939
	2001	5,212,500	3,936
	Average	25,412,500	2,999
3	1996	3,137,500	4,539
	1997	3,637,500	3,945
	1998	3,137,500	5,004
	1999	4,637,500	4,177
	2000	3,887,500	4,361
	2001	1,775,000	4,298
	Average	20,212,500	4,366
4	1996	412,500	4,100
	1997	275,000	1,000
	1998	275,000	3,400
	1999	275,000	2,000
	2000	275,000	2,600
	2001	275,000	2,340
	Average	1,787,500	2,691
5	1996	1,912,500	3,002
	1997	3,550,000	2,268
	1998	1,550,000	3,077
	1999	1,550,000	2,065
	2000	--	--
	2001	--	--
	Average	8,562,500	2,541
U.S.	1996	15,925,000	3,641
	1997	16,237,500	2,849
	1998	10,875,000	3,886
	1999	13,650,000	3,148
	2000	23,600,000	3,442
	2001	12,200,000	3,596

1	1996	7,637,500	3,423
	1997	6,000,000	2,663
	1998	4,637,500	3,998
	1999	4,275,000	3,474
	2000	9,025,000	3,653
	2001	4,937,500	3,055
	Average	36,512,500	3,384
2	1996	2,825,000	3,600
	1997	2,775,000	2,740
	1998	1,275,000	1,818
	1999	2,912,500	1,717
	2000	10,412,500	2,939
	2001	5,212,500	3,936
	Average	25,412,500	2,999
3	1996	3,137,500	4,539
	1997	3,637,500	3,945
	1998	3,137,500	5,004
	1999	4,637,500	4,177
	2000	3,887,500	4,361
	2001	1,775,000	4,298
	Average	20,212,500	4,366
4	1996	412,500	4,100
	1997	275,000	1,000
	1998	275,000	3,400
	1999	275,000	2,000
	2000	275,000	2,600
	2001	275,000	2,340
	Average	1,787,500	2,691
5	1996	1,912,500	3,002
	1997	3,550,000	2,268
	1998	1,550,000	3,077
	1999	1,550,000	2,065
	Average	92,487,500	3,401

500 ppm Low-Sulfur Diesel Fuel. The in-use sulfur level of diesel fuel meeting a 500 ppm sulfur standard is 340 ppm. This in-use level, which is based on fuel survey data from NIPER, the American Automobile Manufacturers Association (AAMA), and the American Petroleum Institute (API) / National Petrochemical and Refiners Association (NPRA), is documented in the Final Regulatory Impact Analysis for the emission standards and diesel fuel sulfur requirements affecting 2007 and later heavy-duty highway engines and vehicles.[8]

California 500 ppm Low-Sulfur Diesel Fuel. The in-use sulfur level of diesel fuel meeting a 500 ppm sulfur standard in California is 120 ppm. A level of 140 ppm was previously estimated in the Final Regulatory Impact Analysis for the emission standards and diesel fuel sulfur requirements affecting 2007 and later heavy-duty highway engines and vehicles.[8] However, more recent in-use survey data shows a constantly decreasing sulfur level in California under this standard. Therefore, it is estimated that California will experience an in-use sulfur level of 120 ppm for diesel fuel complying with the 500 ppm sulfur standard in that state.

11 ppm Low-Sulfur Diesel Fuel. It is estimated that refiners will produce diesel fuel with approximately 7-8 ppm sulfur in order for all parties downstream of the refinery gate to meet the 15 ppm sulfur standard. The actual in-use level likely will be somewhere between 7 and 15 ppm. In complex distribution segments, diesel fuel could have a sulfur level close to the 15 ppm sulfur cap due to contamination that occurs throughout the distribution system. On the other hand, simple distribution segments should not experience as much contamination and the resulting sulfur level should not be as high. On average we expect the in-use sulfur level to be approximately 10 ppm. For emissions inventory modeling purposes, 1 ppm sulfur is added to the in-use fuel sulfur level to account for the combustion of lubricating oil in non-highway engines. Therefore, an 11 ppm total sulfur concentration is used to evaluate the effects on emissions of a fuel complying with a 15 ppm sulfur standard.

Spillover Percentages. The average spillover percentages for the land-based nonroad engines and separately for locomotives and marine vessels are calculated by summing the spillover volume for all the PADDs and dividing by the total volume of either land-based nonroad or locomotives and marine volume for all the PADDs. This approach yields slightly different spillover percentages for 50-state and 48-state cases, so as a simplifying assumption in this analysis, the average of these two spillover percentages was used in both cases.

The estimated average in-use sulfur levels of the highway spillover diesel fuel are estimated by applying the sulfur factors shown in Table 7.1-18 to the phase-in schedule for the highway fuel sulfur standards, which were promulgated in 2001 [66 FR 5002]. The results are described in Table 7.1-20.

Estimating the average in-use sulfur levels of non-highway diesel fuel also involves three transitions when fuel sulfur levels are moving from uncontrolled to a proposed standard, or from one proposed control level to the next. The sulfur levels for these transitions are calculated using the information from Table 7.1-21 with the assumption that any fuel transition occurs in June of the calendar year in which the new standard takes effect. Table 7.1-21 displays the resulting transitional year non-highway fuel sulfur levels.

The information described above is used in the next section to calculate the resulting annual in-use sulfur levels for each.

Table 7.1-20
Average Sulfur Level for On-highway Fuel

Year	Average sulfur (ppm)	Explanation
2005 and earlier	340	Nationwide average, excluding California, prior to introduction of 15ppm standard. This is used in the 48-state and 50-state analyses.
2005 and earlier	300	Nationwide average, including California, prior to introduction of 15ppm standard. Assumes 10% of nationwide highway diesel meets California's requirements. This is used in the 49-state analysis.
2006	165	15ppm standard applies beginning in June. Only 80% of the pool meets the 15ppm standard.
2007	69	Only 80% of the pool meets the 15ppm standard.
2008	69	Only 80% of the pool meets the 15ppm standard.
2009	69	Only 80% of the pool meets the 15ppm standard.
2010 and later	11	100% of the pool meets the 15ppm standard

Table 7.1-21
Average Sulfur Levels for Off-highway Fuel Sulfur Standard Transitions (ppm)

	Uncontrolled to 500ppm standard	500ppm standard to 15ppm standard	Uncontrolled to 15ppm standard
Prior to transition year	3400	340	3400
Transition year	1615	148	1423
After transition year	340	11	11

7.1.4.3 Summary of Annual Diesel Fuel Demand and Sulfur Levels

Tables 7.1-22 through 30 present the diesel demand volumes and average in-use sulfur levels for each year, end use category, and area of interest (50-state, 49-state without California, and 48-state without Alaska or Hawaii). The demand volumes are determined by applying the growth rates from Table 7.1-17 to the 2008 demand volumes shown in Table 7.1-16. The average in-use sulfur concentrations are found by combining the average sulfur levels for highway fuel shown in Table 7.1-20 with the average sulfur levels for non-highway fuel from Table 7.1-21. The spillover fractions given in Table 7.1-18 are used to properly weight the highway and non-highway sulfur levels.

The column headings in the subsequent tables are defined as follows. "Affected Volume" refers to the fuel produced to meet applicable nonroad fuel sulfur requirements. The term

"Spillover" refers to fuel produced to meet highway sulfur requirements, but which ends up being used in nonroad equipment. The final columns labeled "Combo S ppm" show the fuel volume-weighted average sulfur levels for the combination of the "Affected Volume" and the "Spillover Volume." The final “Combo S ppm” columns are the sulfur levels that were used for the 50-state and 48-state emissions inventory modeling. Separate 49-state (without California) emissions modeling was not conducted. Note that the 50-state and 48-state Base and Control combination sulfur levels have been set to the average of the 50 & 48-state values, since the difference was negligible. Similarly, the Locomotive and Marine combination sulfur levels have been set to their average to simplify the analysis.

Table 7.1-22
50-State Nonroad Land-based Diesel Fuel Volumes and Sulfur Content

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm[a]	Control Combo S ppm[a]
2000	8,255	5,384	3400	3400	2,871	300	2318	2318
2001	8,492	5,539	3400	3400	2,953	300	2318	2318
2002	8,730	5,694	3400	3400	3,036	300	2318	2318
2003	8,967	5,849	3400	3400	3,118	300	2318	2318
2004	9,204	6,004	3400	3400	3,201	300	2318	2318
2005	9,442	6,158	3400	3400	3,283	300	2318	2318
2006	9,678	6,312	3400	3400	3,365	165	2271	2271
2007	9,913	6,466	3400	1615	3,447	69	2237	1075
2008	10,149	6,620	3400	340	3,529	69	2237	245
2009	10,385	6,773	3400	340	3,611	69	2237	245
2010	10,620	6,927	3400	148	3,693	11	2217	100
2011	10,857	7,082	3400	11	3,776	11	2217	11
2012	11,094	7,236	3400	11	3,858	11	2217	11
2013	11,331	7,391	3400	11	3,940	11	2217	11
2014	11,568	7,545	3400	11	4,023	11	2217	11
2015	11,805	7,700	3400	11	4,105	11	2217	11
2016	12,040	7,853	3400	11	4,187	11	2217	11
2017	12,275	8,006	3400	11	4,269	11	2217	11
2018	12,509	8,159	3400	11	4,350	11	2217	11
2019	12,744	8,312	3400	11	4,432	11	2217	11
2020	12,979	8,465	3400	11	4,513	11	2217	11
2021	13,214	8,619	3400	11	4,595	11	2217	11
2022	13,448	8,772	3400	11	4,677	11	2217	11
2023	13,683	8,925	3400	11	4,758	11	2217	11
2024	13,918	9,078	3400	11	4,840	11	2217	11
2025	14,153	9,231	3400	11	4,922	11	2217	11
2026	14,386	9,383	3400	11	5,003	11	2217	11
2027	14,619	9,535	3400	11	5,084	11	2217	11
2028	14,852	9,687	3400	11	5,165	11	2217	11
2029	15,085	9,839	3400	11	5,246	11	2217	11
2030	15,319	9,992	3400	11	5,327	11	2217	11
2031	15,552	10,144	3400	11	5,408	11	2217	11
2032	15,785	10,296	3400	11	5,489	11	2217	11
2033	16,018	10,448	3400	11	5,570	11	2217	11
2034	16,252	10,600	3400	11	5,652	11	2217	11
2035	16,485	10,752	3400	11	5,733	11	2217	11
2036	16,718	10,904	3400	11	5,814	11	2217	11
2037	16,951	11,056	3400	11	5,895	11	2217	11
2038	17,185	11,209	3400	11	5,976	11	2217	11
2039	17,418	11,361	3400	11	6,057	11	2217	11
2040	17,651	11,513	3400	11	6,138	11	2217	11

[a] 50-state and 48-state Base and Control combination sulfur levels have been set to the average of 50 & 48-state values, since the difference was negligible.

Table 7.1-23
50-State Locomotive Diesel Fuel Volumes and Sulfur Content

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm[a]	Control Combo S ppm[a]
2000	2825	1836	3400	3400	989	299	2396	2396
2001	2,970	1931	3400	3400	1,040	299	2396	2396
2002	2,922	1,899	3400	3400	1,023	299	2396	2396
2003	2,973	1,932	3400	3400	1,040	299	2396	2396
2004	3,014	1,959	3400	3400	1,055	299	2396	2396
2005	3,055	1,986	3400	3400	1,069	299	2396	2396
2006	3,085	2,005	3400	3400	1,080	165	2352	2352
2007	3,115	2,025	3400	1615	1,090	69	2321	1114
2008	3,129	2,034	3400	340	1,095	69	2321	252
2009	3,150	2,048	3400	340	1,102	69	2321	252
2010	3,173	2,063	3400	340	1,110	11	2302	233
2011	3,227	2,098	3400	340	1,129	11	2302	233
2012	3,242	2,107	3400	340	1,134	11	2302	233
2013	3,251	2,113	3400	340	1,138	11	2302	233
2014	3,260	2,119	3400	340	1,141	11	2302	233
2015	3,274	2,128	3400	340	1,146	11	2302	233
2016	3,308	2,150	3400	340	1,158	11	2302	233
2017	3,327	2,163	3400	340	1,164	11	2302	233
2018	3,344	2,174	3400	340	1,170	11	2302	233
2019	3,363	2,186	3400	340	1,177	11	2302	233
2020	3,374	2,193	3400	340	1,181	11	2302	233
2021	3,404	2,213	3400	340	1,191	11	2302	233
2022	3,434	2,233	3400	340	1,202	11	2302	233
2023	3,465	2,252	3400	340	1,213	11	2302	233
2024	3,496	2,273	3400	340	1,223	11	2302	233
2025	3,527	2,293	3400	340	1,234	11	2302	233
2026	3,559	2,313	3400	340	1,245	11	2302	233
2027	3,590	2,334	3400	340	1,256	11	2302	233
2028	3,622	2,355	3400	340	1,268	11	2302	233
2029	3,655	2,376	3400	340	1,279	11	2302	233
2030	3,687	2,397	3400	340	1,290	11	2302	233
2031	3,720	2,418	3400	340	1,302	11	2302	233
2032	3,753	2,440	3400	340	1,314	11	2302	233
2033	3,787	2,462	3400	340	1,325	11	2302	233
2034	3,821	2,484	3400	340	1,337	11	2302	233
2035	3,855	2,506	3400	340	1,349	11	2302	233
2036	3,889	2,528	3400	340	1,361	11	2302	233
2037	3,924	2,551	3400	340	1,373	11	2302	233
2038	3,959	2,573	3400	340	1,385	11	2302	233
2039	3,994	2,596	3400	340	1,398	11	2302	233
2040	4030	2,620	3400	340	1,410	11	2302	233

[a] 50-state and 48-state Base and Control combination sulfur levels have been set to the average of 50 & 48-state values, since the difference was negligible. Similarly, the Locomotive and Marine combination sulfur levels have been set to their average to simplify the analysis.

Table 7.1-24
50-State Marine Diesel Fuel Volumes and Sulfur Content

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm[a]	Control Combo S ppm[a]
2000	1870	1,350	3400	3400	519	299	2396	2396
2001	1,890	1,365	3400	3400	525	299	2396	2396
2002	1,911	1,380	3400	3400	530	299	2396	2396
2003	1,931	1,395	3400	3400	536	299	2396	2396
2004	1,953	1,410	3400	3400	542	299	2396	2396
2005	1,974	1,426	3400	3400	548	299	2396	2396
2006	1,996	1,442	3400	3400	554	165	2352	2352
2007	2,018	1,458	3400	1615	560	69	2321	1114
2008	2,040	1,474	3400	340	567	69	2321	252
2009	2,063	1,490	3400	340	573	69	2321	252
2010	2,086	1,507	3400	340	579	11	2302	233
2011	2,109	1,523	3400	340	586	11	2302	233
2012	2,132	1,540	3400	340	592	11	2302	233
2013	2,156	1,557	3400	340	599	11	2302	233
2014	2,180	1,575	3400	340	605	11	2302	233
2015	2,205	1,593	3400	340	612	11	2302	233
2016	2,230	1,610	3400	340	619	11	2302	233
2017	2,255	1,629	3400	340	626	11	2302	233
2018	2,280	1,647	3400	340	633	11	2302	233
2019	2,306	1,666	3400	340	640	11	2302	233
2020	2,333	1,685	3400	340	648	11	2302	233
2021	2,359	1,704	3400	340	655	11	2302	233
2022	2,387	1,724	3400	340	663	11	2302	233
2023	2,414	1,744	3400	340	670	11	2302	233
2024	2,442	1,764	3400	340	678	11	2302	233
2025	2,471	1,785	3400	340	686	11	2302	233
2026	2,499	1,805	3400	340	694	11	2302	233
2027	2,529	1,827	3400	340	702	11	2302	233
2028	2,559	1,848	3400	340	710	11	2302	233
2029	2,589	1,870	3400	340	719	11	2302	233
2030	2,620	1,892	3400	340	727	11	2302	233
2031	2,651	1,915	3400	340	736	11	2302	233
2032	2,683	1,938	3400	340	745	11	2302	233
2033	2,715	1,961	3400	340	754	11	2302	233
2034	2,748	1,985	3400	340	763	11	2302	233
2035	2,781	2,009	3400	340	772	11	2302	233
2036	2,815	2,033	3400	340	782	11	2302	233
2037	2,850	2,058	3400	340	791	11	2302	233
2038	2,885	2,084	3400	340	801	11	2302	233
2039	2,920	2,110	3400	340	811	11	2302	233
2040	2,957	2136	3400	340	821	11	2302	233

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[a] 50-state and 48-state Base and Control combination sulfur levels have been set to the average of 50 & 48-state values, since the difference was negligible. Similarly, the Locomotive and Marine combination sulfur levels have been set to their average to simplify the analysis.

Table 7.1-25
49-State Nonroad Land-based Diesel Fuel Volumes and Sulfur Content[a]

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm	Control Combo S ppm
2000	7716	5,384	3400	3400	2,332	340	2475	2475
2001	7938	5,539	3400	3400	2,399	340	2475	2475
2002	8,160	5,694	3400	3400	2,466	340	2475	2475
2003	8,382	5,849	3400	3400	2,533	340	2475	2475
2004	8,603	6,004	3400	3400	2,600	340	2475	2475
2005	8,825	6,158	3400	3400	2,667	340	2475	2475
2006	9,046	6,312	3400	3400	2,734	186	2429	2429
2007	9,266	6,466	3400	1615	2,800	77	2396	1150
2008	9,486	6,620	3400	340	2,867	77	2396	260
2009	9,707	6,773	3400	340	2,933	77	2396	260
2010	9,927	6,927	3400	148	3,000	11	2376	107
2011	10,149	7,082	3400	11	3,067	11	2376	11
2012	10,370	7,236	3400	11	3,134	11	2376	11
2013	10,591	7,391	3400	11	3,201	11	2376	11
2014	10,813	7,545	3400	11	3,268	11	2376	11
2015	11,034	7,700	3400	11	3,334	11	2376	11
2016	11,254	7,853	3400	11	3,401	11	2376	11
2017	11,473	8,006	3400	11	3,467	11	2376	11
2018	11,693	8,159	3400	11	3,533	11	2376	11
2019	11,912	8,312	3400	11	3,600	11	2376	11
2020	12,131	8,465	3400	11	3,666	11	2376	11
2021	12,351	8,619	3400	11	3,732	11	2376	11
2022	12,570	8,772	3400	11	3,799	11	2376	11
2023	12,790	8,925	3400	11	3,865	11	2376	11
2024	13,009	9,078	3400	11	3,931	11	2376	11
2025	13,228	9,231	3400	11	3,998	11	2376	11
2026	13,446	9,383	3400	11	4,063	11	2376	11
2027	13,664	9,535	3400	11	4,129	11	2376	11
2028	13,882	9,687	3400	11	4,195	11	2376	11
2029	14,100	9,839	3400	11	4,261	11	2376	11
2030	14,318	9,992	3400	11	4,327	11	2376	11
2031	14,536	10,144	3400	11	4,393	11	2376	11
2032	14,754	10,296	3400	11	4,459	11	2376	11
2033	14,972	10,448	3400	11	4525	11	2376	11
2034	15,190	10,600	3400	11	4,590	11	2376	11
2035	15,408	10,752	3400	11	4,656	11	2376	11
2036	15,626	10,904	3400	11	4,722	11	2376	11
2037	15,844	11,056	3400	11	4,788	11	2376	11
2038	16,062	11,209	3400	11	4,854	11	2376	11
2039	16,280	11,361	3400	11	4,920	11	2376	11
2040	16,498	11,513	3400	11	4,986	11	2376	11

[a] 49-state analysis includes all states except California.

Table 7.1-26

49-State Locomotive Diesel Fuel Volumes and Sulfur Content[a]

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm	Control Combo S ppm
2000	2651	1,836	3400	3400	815	340	2460	2460
2001	2,787	1,931	3400	3400	856	340	2460	2460
2002	2,742	1,899	3400	3400	842	340	2460	2460
2003	2,790	1,932	3400	3400	857	340	2460	2460
2004	2,828	1,959	3400	3400	869	340	2460	2460
2005	2,867	1,986	3400	3400	881	340	2460	2460
2006	2,895	2,005	3400	3400	889	186	2413	2413
2007	2,923	2,025	3400	1615	898	77	2379	1142
2008	2,936	2,034	3400	340	902	77	2379	259
2009	2,956	2,048	3400	340	908	77	2379	259
2010	2,977	2,063	3400	340	915	11	2359	239
2011	3,028	2,098	3400	340	930	11	2359	239
2012	3,042	2,107	3400	340	935	11	2359	239
2013	3,050	2,113	3400	340	937	11	2359	239
2014	3,059	2,119	3400	340	940	11	2359	239
2015	3,073	2,128	3400	340	944	11	2359	239
2016	3,104	2,150	3400	340	954	11	2359	239
2017	3,122	2,163	3400	340	959	11	2359	239
2018	3,138	2,174	3400	340	964	11	2359	239
2019	3,156	2,186	3400	340	970	11	2359	239
2020	3,166	2,193	3400	340	973	11	2359	239
2021	3,194	2,213	3400	340	982	11	2359	239
2022	3,223	2,233	3400	340	990	11	2359	239
2023	3,252	2,252	3400	340	999	11	2359	239
2024	3,281	2,273	3400	340	1,008	11	2359	239
2025	3,310	2,293	3400	340	1,017	11	2359	239
2026	3,339	2,313	3400	340	1,026	11	2359	239
2027	3,369	2,334	3400	340	1,035	11	2359	239
2028	3,399	2,355	3400	340	1,044	11	2359	239
2029	3,430	2,376	3400	340	1,054	11	2359	239
2030	3,460	2,397	3400	340	1,063	11	2359	239
2031	3,491	2,418	3400	340	1,073	11	2359	239
2032	3,522	2,440	3400	340	1,082	11	2359	239
2033	3,554	2,462	3400	340	1,092	11	2359	239
2034	3,585	2,484	3400	340	1102	11	2359	239
2035	3,617	2,506	3400	340	1,111	11	2359	239
2036	3,650	2,528	3400	340	1,121	11	2359	239
2037	3,682	2,551	3400	340	1,131	11	2359	239
2038	3,715	2,573	3400	340	1,142	11	2359	239
2039	3,748	2,596	3400	340	1,152	11	2359	239
2040	3,782	2,620	3400	340	1,162	11	2359	239

[a] 49-state analysis includes all states except California.

Table 7.1-27
49-State Marine Diesel Fuel Volumes and Sulfur Content[a]

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm	Control Combo S ppm
2000	1779	1,350	3400	3400	428	340	2663	2663
2001	1,798	1,365	3400	3400	433	340	2663	2663
2002	1,818	1,380	3400	3400	438	340	2663	2663
2003	1,838	1,395	3400	3400	442	340	2663	2663
2004	1,858	1,410	3400	3400	447	340	2663	2663
2005	1,878	1,426	3400	3400	452	340	2663	2663
2006	1,899	1,442	3400	3400	457	186	2626	2626
2007	1,920	1,458	3400	1615	462	77	2600	1245
2008	1,941	1,474	3400	340	467	77	2600	277
2009	1,963	1,490	3400	340	473	77	2600	277
2010	1,984	1,507	3400	340	478	11	2584	261
2011	2,006	1,523	3400	340	483	11	2584	261
2012	2,029	1,540	3400	340	488	11	2584	261
2013	2,051	1,557	3400	340	494	11	2584	261
2014	2,074	1,575	3400	340	499	11	2584	261
2015	2,098	1,593	3400	340	505	11	2584	261
2016	2,121	1,610	3400	340	511	11	2584	261
2017	2,145	1,629	3400	340	516	11	2584	261
2018	2,170	1,647	3400	340	522	11	2584	261
2019	2,194	1,666	3400	340	528	11	2584	261
2020	2,219	1,685	3400	340	534	11	2584	261
2021	2,245	1,704	3400	340	540	11	2584	261
2022	2,271	1,724	3400	340	547	11	2584	261
2023	2,297	1,744	3400	340	553	11	2584	261
2024	2,323	1,764	3400	340	559	11	2584	261
2025	2,350	1,785	3400	340	566	11	2584	261
2026	2,378	1,805	3400	340	573	11	2584	261
2027	2,406	1,827	3400	340	579	11	2584	261
2028	2,434	1,848	3400	340	586	11	2584	261
2029	2,463	1,870	3400	340	593	11	2584	261
2030	2,492	1,892	3400	340	600	11	2584	261
2031	2,522	1,915	3400	340	607	11	2584	261
2032	2,552	1,938	3400	340	614	11	2584	261
2033	2,583	1,961	3400	340	622	11	2584	261
2034	2,614	1,985	3400	340	629	11	2584	261
2035	2,646	2,009	3400	340	637	11	2584	261
2036	2,678	2,033	3400	340	645	11	2584	261
2037	2,711	2,058	3400	340	653	11	2584	261
2038	2,744	2,084	3400	340	661	11	2584	261
2039	2,778	2,110	3400	340	669	11	2584	261
2040	2,813	2,136	3400	340	677	11	2584	261

[a] 49-state analysis includes all states except California.

Table 7.1-28

48-State Nonroad Land-based Diesel Fuel Volumes and Sulfur Content[a]

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm[b]	Control Combo S ppm[b]
2000	8,175	5,315	3400	3400	2,860	299	2318	2318
2001	8,410	5,468	3400	3400	2,942	299	2318	2318
2002	8,645	5,621	3400	3400	3,025	299	2318	2318
2003	8,880	5,773	3400	3400	3,107	299	2318	2318
2004	9,115	5,926	3400	3400	3,189	299	2318	2318
2005	9,350	6,079	3400	3400	3,271	299	2318	2318
2006	9,584	6,231	3400	3400	3,353	165	2271	2271
2007	9,817	6,383	3400	1615	3,435	69	2237	1075
2008	10,051	6,534	3400	340	3,516	69	2237	245
2009	10,284	6,686	3400	340	3598	69	2237	245
2010	10,518	6,838	3400	148	3,680	11	2217	100
2011	10,752	6,990	3400	11	3,762	11	2217	11
2012	10,987	7,143	3400	11	3,844	11	2217	11
2013	11,222	7,296	3400	11	3,926	11	2217	11
2014	11,456	7,448	3400	11	4,008	11	2217	11
2015	11,691	7,601	3400	11	4,090	11	2217	11
2016	11,923	7,752	3400	11	4,172	11	2217	11
2017	12,156	7,903	3400	11	4,253	11	2217	11
2018	12,388	8,054	3400	11	4,334	11	2217	11
2019	12,621	8,205	3400	11	4,415	11	2217	11
2020	12,853	8,356	3400	11	4,497	11	2217	11
2021	13,086	8,507	3400	11	4,578	11	2217	11
2022	13,318	8,659	3400	11	4,659	11	2217	11
2023	13,550	8,810	3400	11	4,741	11	2217	11
2024	13,783	8,961	3400	11	4,822	11	2217	11
2025	14,015	9,112	3400	11	4,903	11	2217	11
2026	14,246	9,262	3400	11	4,984	11	2217	11
2027	14,477	9,412	3400	11	5,065	11	2217	11
2028	14,708	9,562	3400	11	5,146	11	2217	11
2029	14,939	9,713	3400	11	5,227	11	2217	11
2030	15,170	9,863	3400	11	5,307	11	2217	11
2031	15,401	10,013	3400	11	5,388	11	2217	11
2032	15,632	10,163	3400	11	5,469	11	2217	11
2033	15,863	10,313	3400	11	5,550	11	2217	11
2034	16,094	10,463	3400	11	5,631	11	2217	11
2035	16,325	10,614	3400	11	5712	11	2217	11
2036	16,556	10,764	3400	11	5,792	11	2217	11
2037	16,787	10,914	3400	11	5,873	11	2217	11
2038	17018	11,064	3400	11	5,954	11	2217	11
2039	17,249	11,214	3400	11	6,035	11	2217	11
2040	17,480	11,364	3400	11	6,116	11	2217	11

[a] 48-state analysis includes all states except Alaska and Hawaii.

[b] 50-state and 48-state Base and Control combination sulfur levels have been set to the average of 50 and 48-state values, since the difference was negligible.

Table 7.1-29
48-State Locomotive Diesel Fuel Volumes and Sulfur Content[a]

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm[b]	Control Combo S ppm[b]
2000	2821	1,833	3400	3400	988	299	2396	2396
2001	2966	1,927	3400	3400	1,039	299	2396	2396
2002	2,918	1,896	3400	3400	1,022	299	2396	2396
2003	2969	1,929	3400	3400	1,040	299	2396	2396
2004	3,010	1,955	3400	3400	1,054	299	2396	2396
2005	3,051	1,982	3400	3400	1,069	299	2396	2396
2006	3,081	2,001	3400	3400	1079	165	2352	2352
2007	3,111	2,021	3400	1615	1,090	69	2321	1114
2008	3,124	2,030	3400	340	1,095	69	2321	252
2009	3,146	2,044	3400	340	1102	69	2321	252
2010	3,169	2,058	3400	340	1,110	11	2302	233
2011	3,223	2,094	3400	340	1,129	11	2302	233
2012	3,237	2,103	3400	340	1,134	11	2302	233
2013	3,246	2,109	3400	340	1,137	11	2302	233
2014	3,255	2,115	3400	340	1,140	11	2302	233
2015	3,270	2,124	3400	340	1,146	11	2302	233
2016	3,303	2,146	3400	340	1,157	11	2302	233
2017	3,322	2,158	3400	340	1,164	11	2302	233
2018	3,340	2,169	3400	340	1,170	11	2302	233
2019	3,358	2,182	3400	340	1,177	11	2302	233
2020	3,369	2,189	3400	340	1,181	11	2302	233
2021	3,399	2,208	3400	340	1,191	11	2302	233
2022	3,430	2,228	3400	340	1,202	11	2302	233
2023	3,460	2,248	3400	340	1,212	11	2302	233
2024	3,491	2,268	3400	340	1,223	11	2302	233
2025	3,522	2,288	3400	340	1,234	11	2302	233
2026	3,554	2,309	3400	340	1,245	11	2302	233
2027	3585	2,329	3400	340	1,256	11	2302	233
2028	3,617	2,350	3400	340	1,267	11	2302	233
2029	3,650	2,371	3400	340	1,279	11	2302	233
2030	3,682	2,392	3400	340	1,290	11	2302	233
2031	3,715	2,413	3400	340	1,302	11	2302	233
2032	3748	2,435	3400	340	1,313	11	2302	233
2033	3,782	2,457	3400	340	1,325	11	2302	233
2034	3,815	2,479	3400	340	1,337	11	2302	233
2035	3,849	2,501	3400	340	1,349	11	2302	233
2036	3,884	2,523	3400	340	1,361	11	2302	233
2037	3,918	2,546	3400	340	1,373	11	2302	233
2038	3,953	2,568	3400	340	1,385	11	2302	233
2039	3,989	2,591	3400	340	1,398	11	2302	233
2040	4,024	2614	3400	340	1410	11	2302	233

[a] 48-state analysis includes all states except Alaska and Hawaii.

[b] 50-state and 48-state Base and Control combination sulfur levels have been set to the average of 50 & 48-state values, since the difference was negligible. Similarly, the Locomotive and Marine combination sulfur levels have been set to their average to simplify the analysis.

Table 7.1-30
48-State Marine Diesel Fuel Volumes and Sulfur Content[a]

Year	Total Volume	Affected Volume	Base S ppm	Control S ppm	Spillover Volume	Spillover S ppm	Base Combo S ppm[b]	Control Combo S ppm[b]
2000	1786	1,273	3400	3400	513	299	2396	2396
2001	1,805	1,287	3400	3400	518	299	2396	2396
2002	1,825	1,301	3400	3400	524	299	2396	2396
2003	1,845	1,315	3400	3400	530	299	2396	2396
2004	1,865	1,330	3400	3400	535	299	2396	2396
2005	1,886	1,344	3400	3400	541	299	2396	2396
2006	1,906	1,359	3400	3400	547	165	2352	2352
2007	1,928	1,374	3400	1615	553	69	2321	1114
2008	1,949	1,389	3400	340	560	69	2321	252
2009	1,970	1,405	3400	340	566	69	2321	252
2010	1,992	1,420	3400	340	572	11	2302	233
2011	2,014	1,436	3400	340	578	11	2302	233
2012	2,037	1,452	3400	340	585	11	2302	233
2013	2,059	1,468	3400	340	591	11	2302	233
2014	2,082	1,485	3400	340	598	11	2302	233
2015	2,106	1,501	3400	340	605	11	2302	233
2016	2,130	1,518	3400	340	611	11	2302	233
2017	2,154	1,535	3400	340	618	11	2302	233
2018	2,178	1,553	3400	340	625	11	2302	233
2019	2,203	1,570	3400	340	632	11	2302	233
2020	2,228	1,588	3400	340	640	11	2302	233
2021	2,254	1,607	3400	340	647	11	2302	233
2022	2,279	1,625	3400	340	654	11	2302	233
2023	2,306	1,644	3400	340	662	11	2302	233
2024	2,333	1,663	3400	340	670	11	2302	233
2025	2,360	1,682	3400	340	677	11	2302	233
2026	2,387	1,702	3400	340	685	11	2302	233
2027	2,415	1,722	3400	340	693	11	2302	233
2028	2,444	1,742	3400	340	702	11	2302	233
2029	2,473	1,763	3400	340	710	11	2302	233
2030	2,502	1,784	3400	340	718	11	2302	233
2031	2,532	1,805	3400	340	727	11	2302	233
2032	2,562	1,827	3400	340	736	11	2302	233
2033	2,593	1,849	3400	340	745	11	2302	233
2034	2,624	1,871	3400	340	754	11	2302	233
2035	2,656	1,894	3400	340	763	11	2302	233
2036	2,689	1,917	3400	340	772	11	2302	233
2037	2,722	1,940	3400	340	781	11	2302	233
2038	2,755	1,964	3400	340	791	11	2302	233
2039	2,789	1,989	3400	340	801	11	2302	233
2040	2,824	2013	3400	340	811	11	2302	233

[a] 48-state analysis includes all states except Alaska and Hawaii.

[b] 50-state and 48-state Base and Control combination sulfur levels have been set to the average of 50 & 48-state values, since the difference was negligible. Similarly, the Locomotive and Marine combination sulfur levels have been set to their average to simplify the analysis.

7.1.5 Refinery Supply Volumes

After developing the 2008 volume estimates for the consumption of highway diesel fuel; nonroad, locomotive and marine diesel fuel and other non-highway distillate fuel, it was necessary to estimate the refinery supply volumes for each of these subpools to develop a baseline for the refinery cost analysis for the proposed rule. The refinery supply volumes are different from the consumption volumes because of the downgrade which occurs from the low sulfur highway diesel fuel pool to the high sulfur non-highway diesel fuel pool during the distribution between the refineries and the terminals. For the highway diesel rule promulgated in 2001, EPA estimated that downgrade would increase by 2.2 percent due to the 15 ppm highway diesel fuel sulfur standard which takes effect in 2006. EPA also estimated that there is already a 2.2 percent downgrade due to the current 500 ppm sulfur which results in a total of 4.4 percent downgrade from the highway diesel fuel pool to the non-highway distillate pool. The 4.4 percent downgrade was applied equally in each PADD and the resulting volumes are representative after any inter-PADD transfers have taken place. While the downgrade has not yet occurred in the refinery supply table, the spillover volume is considered the same between the two tables as this volume is an intended transfer from the highway to the nonroad diesel pool to avoid having to invest capital investments in the distribution system.

The 4.4 percent highway downgrade is accounted for by dividing the highway diesel fuel demand volume by 95.6 percent, and the downgraded highway diesel fuel was then added to the high sulfur distillate fuel pool. The highway diesel fuel downgrade is presumed to all go to the other non-highway distillate fuel (i.e., heating oil). This is a conservative estimate as it is likely that much of this downgraded volume would be under 500 ppm and could be downgraded to the 500 ppm pools, either the 500 ppm highway, nonroad, locomotive and marine diesel pools from 2006 to 2010, or to the 500 ppm locomotive and marine pool after 2010. This assumption will be reconsidered for the final rule.

The sulfur levels of the spillover volume for the refinery supply estimates were determined differently from the fuel demand estimates, which assumed the same proportion of highway 15/500 ppm fuel in each non-highway subpool as in the highway pool. For the supply estimates, we presumed all spillover into the NRLM diesel fuel is 15 ppm.

The result of the these adjustments in pool volumes to account for the downgrade in the distribution system is summarized in Table 7.1-31. These are the diesel fuel volumes that were used in the subsequent cost analysis.

Table 7.1-31
Summary of Diesel Fuel Supply by PADD for 2008 (million gallons)

Category	Fuel Type	1	2	3	4	5 AZ, NV, OR, WA	5 AK	5 HI	U.S. - CA	5 CA	U.S.
Revised Highway	total	13,000	14,158	7,156	1,859	2,398	115	42	38,728	3,236	41,964
	15ppm diesel	9,647	10,186	5,042	1,199	1,750	84	29	27,938	3,236	31,174
	500ppm diesel	3,353	3,972	2,113	659	648	31	14	10,790	0	10,790
	high S	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Land-Based Nonroad	total	2,166	3,559	2,273	822	567	66	32	9,486	663	10,149
	15ppm diesel	308	1,222	757	548	150	5	9	2,999	663	3,661
	500ppm diesel	0	0	0	0	0	0	0	0	0	0
	high S	1,858	2,337	1,517	274	417	62	23	6,488	0	6,488
Locomotive	total	509	1,256	700	351	116	4	0	2,936	193	3,129
	15ppm diesel	53	410	221	231	29	0	0	944	193	1,136
	500ppm diesel	0	0	0	0	0	0	0	0	0	0
	high S	456	846	479	120	87	4	0	1,992	0	1,992
Marine	total	481	295	1,014	0	60	78	13	1,941	99	2,040
	15ppm diesel	50	96	320	0	15	4	3	489	99	588
	500ppm diesel	0	0	0	0	0	0	0	0	0	0
	high S	431	199	693	0	45	74	10	1,452	0	1,452
Subtotal (NR, Loc, Marine)	total	3,156	5,111	3,987	1,173	743	149	45	14,364	955	15,318
	15ppm diesel	411	1,728	1,298	779	194	9	12	4,431	955	5,386
	500ppm diesel	0	0	0	0	0	0	0	0	0	0
	high S	2,745	3,382	2,689	394	549	140	33	9,932	0	9,932
Other Off-Highway	total	8,001	1,165	785	156	253	148	6	10,514	141	10,654
	15ppm diesel	681	409	247	106	63	6	1	1,513	141	1,654
	500ppm diesel	217	130	79	34	20	2	0	482	0	482
	high S	7,103	627	460	16	169	140	4	8,518	0	8,518
TOTAL	total	24,157	20,434	11,927	3,188	3,394	412	93	63,605	4,332	67,937
	15ppm diesel	10,739	12,323	6,587	2,085	2,008	99	42	33,882	4,332	38,214
	500ppm diesel	3,570	4,102	2,192	693	668	33	14	11,272	0	11,272
	high S	9,848	4,009	3,148	410	718	280	37	18,451	0	18,451

For using the supply volumes in Table 7.1-31 for estimating the cost-effectiveness of the analysis contained in Chapter 8, it is necessary to project the supply volumes into future years for the Proposed Two Step NRLM fuel program and the other options considered. This was done using the applicable growth rates for each respective pool, considering the volume of small refiner NRLM diesel fuel which is exempted from having to comply during the two exemption periods (2007 to 2010, and 2010 to 2014), and considering the increased spillover of 500 ppm and 15 ppm sulfur diesel fuel into the heating oil market. Spillover increases because refineries in PADD 2 and 4 are not expected to be able to sell off their current high sulfur distillate pool solely into the heating oil market.

The following table provide the base volumes used for estimating the total volume of 500 ppm diesel fuel and the total volume of 15 ppm diesel fuel affected by the Proposed Two step Nonroad Program (this table is only shown for the Proposed Two Step fuel program).

Table 7.1-34 Future nonhighway Supply volumes for the U.S. outside of California for the Proposed Two Step NRLM Program (MMGallons/yr)

	Nonroad				Locomotive				Marine				Heating Oil	Heating Oil
Year	Total Volume	HS Pool and Affected Volume	Small Refiner Exempted Volume	Spillover Volume	Total Volume	HS Pool and Affected Volume	Small Refiner Exempted Volume	Spillover Volume	Total Volume	HS Pool and Affected Volume	Small Refiner Exempted Volume	Spillover Volume	Other Affected Volume (new spillover) 500 ppm	Other Affected Volume (new spillover) 15 ppm\
2000	7,716	5,277		2,439	2,651	1,799		852	1,779	1,331		448	0	0
2001	7,938	5,429		2,509	2,787	1,892		896	1,798	1,345		453	0	0
2002	8,160	5,580		2,579	2,742	1,861		881	1,818	1,360		458	0	0
2003	8,382	5,732		2,649	2,790	1,893		897	1,838	1,375		463	0	0
2004	8,603	5,884		2,720	2,828	1,919		909	1,858	1,390		468	0	0
2005	8,825	6,036		2,790	2,867	1,946		922	1,878	1,405		473	0	0
2006	9,046	6,186		2,859	2,895	1,964		930	1,899	1,421		478	0	0
2007	9,266	5,654	683	2,929	2,923	1,770	214	940	1,920	1,282	155	484	636	0
2008	9,486	5,788	700	2,999	2,936	1,778	215	944	1,941	1,296	157	489	642	0
2009	9,707	5,923	716	3,068	2,956	1,790	216	950	1,963	1,310	158	494	648	0
Jan-May '10	9,927	6,057	732	3,138	2,977	1,803	218	957	1,984	1,325	160	500	654	0
Jun-Dec '10	9,927	5,893	1034	3,000	2,977	1,951		1,026	1,984	1,416		569	556	98
2011	10,149	6,025	1057	3,067	3,028	1,985		1,044	2,006	1,431		575	561	99
2012	10,370	6,156	1080	3,134	3,042	1,994		1,048	2,029	1,447		581	567	100
2013	10,591	6,288	1103	3,201	3,050	1,999		1,051	2,051	1,463		588	572	101
Jan-May '14	10,813	6,419	1126	3,268	3,059	2,005		1,054	2,074	1,480		595	577	102
Jun-Dec '14	10,813	7,545		3,268	3,059	2,005		1,054	2,074	1,480		595	577	102
2015	11,034	7,700		3,334	3,073	2,014		1,059	2,098	1,496		601	583	103
2016	11,254	7,853		3,401	3,104	2,034		1,070	2,121	1,513		608	588	104
2017	11,473	8,006		3,467	3,122	2,046		1,076	2,145	1,530		615	593	105
2018	11,693	8,159		3,533	3,138	2,057		1,081	2,170	1,548		622	599	106
2019	11,912	8,312		3,600	3,156	2,068		1,087	2,194	1,565		629	605	107
2020	12,131	8,465		3,666	3,166	2,075		1,091	2,219	1,583		636	610	108
2021	12,351	8,619		3,732	3,194	2,094		1,101	2,245	1,601		643	616	109
2022	12,570	8,772		3,799	3,223	2,112		1,111	2,271	1,620		651	622	110
2023	12,790	8,925		3,865	3,252	2,131		1,120	2,297	1,638		658	627	111
2024	13,009	9,078		3,931	3,281	2,150		1,130	2,323	1,657		666	633	112
2025	13,228	9,231		3,998	3,310	2,169		1,141	2,350	1,677		674	639	113
2026	13,446	9,383		4,063	3,339	2,189		1,151	2,378	1,696		682	645	114
2027	13,664	9,535		4,129	3,369	2,208		1,161	2,406	1,716		690	651	115
2028	13,882	9,687		4,195	3,399	2,228		1,171	2,434	1,736		698	657	116
2029	14,100	9,839		4,261	3,430	2,248		1,182	2,463	1,757		706	663	117
2030	14,318	9,992		4,327	3,460	2,268		1,192	2,492	1,778		714	669	118
2031	14,536	10,144		4,393	3,491	2,288		1,203	2,522	1,799		723	676	119
2032	14,754	10,296		4,459	3,522	2,308		1,214	2,552	1,820		731	682	120
2033	14,972	10,448		4,525	3,553	2,329		1,224	2,582	1,842		740	688	121
2034	15,190	10,600		4,590	3,585	2,350		1,235	2,613	1,864		749	695	123
2035	15,408	10,752		4,656	3,617	2,371		1,246	2,644	1,886		758	701	124
2036	15,626	10,904		4,722	3,649	2,392		1,257	2,675	1,908		767	708	125

The following table summarizes the estimated volume of 500 ppm diesel fuel and 15 ppm diesel fuel affected by the Proposed Two step Nonroad Program by each year from 2007 to 2036. The spillover of highway into the NRLM diesel pools and the total volume of NRLM diesel fuel is also presented.

Table 7.1-35 Future nonhighway Supply volumes for U.S. outside of California for the Proposed Two Step NRLM Program (MMGallons/yr)

Totals (NR, Loc & Mar)

Year	Total Volume	Affected Volume for 500 ppm			Affected Volume for 15 ppm		Spillover Volume
		2007-2010	2010-2014	2014+	2010-2014	2014+	
2000	12,145						3,739
2001	12,523						3,858
2002	12,719						3,918
2003	13,009						4,009
2004	13,289						4,096
2005	13,571						4,184
2006	13,839						4,268
2007	14,745	5,449					4,352
2008	15,006	9,504					4,431
2009	15,274	9,671					4,513
Jan-May '10	15,543	4,099					4,595
Jun-Dec '10	15,543		2,892		3,495		4,595
2011	15,844		5,034		6,124		4,685
2012	16,107		5,088		6,256		4,763
2013	16,366		5,137		6,389		4,840
Jan-May '14	16,625		2,162		2,717		4,916
Jun-Dec '14	16,625			2,369		4,461	4,916
2015	16,890			4,093		7,803	4,995
2016	17,171			4,136		7,957	5,078
2017	17,438			4,170		8,111	5,158
2018	17,705			4,203		8,265	5,237
2019	17,973			4,238		8,419	5,316
2020	18,235			4,268		8,573	5,393
2021	18,514			4,311		8,727	5,476
2022	18,795			4,354		8,881	5,560
2023	19,076			4,397		9,035	5,644
2024	19,358			4,441		9,190	5,728
2025	19,641			4,485		9,344	5,812
2026	19,923			4,530		9,497	5,896
2027	20,205			4,575		9,650	5,980
2028	20,489			4,621		9,803	6,064
2029	20,773			4,668		9,956	6,149
2030	21,058			4,715		10,110	6,234
2031	21,344			4,763		10,263	6,319
2032	21,631			4,811		10,416	6,404
2033	21,918			4,859		10,569	6,489
2034	22,205			4,908		10,723	6,575
2035	22,494			4,958		10,876	6,660
2036	22,783			5,008		11,029	6,746

The following table summarizes the estimated volume of 500 ppm diesel fuel and 15 ppm diesel fuel affected by the One step Nonroad Program (Option #1) by each year from 2008 to 2036. The spillover of highway into the NRLM diesel pools and the total volume of NRLM diesel fuel is also presented.

Table 7.1-36 - Future nonhighway Supply volumes for the U.S. outside of California for the One Step Program with Locomotive and Marine to 500 and NR to 15 in 2008 (MMGallons/yr)

Totals (NR, Loc & Mar)						
Year	Total Volume	Affected Volume for 500 ppm		Affected Volume for 15 ppm		Spillover Volume
		2008-2012	2012+	2008-2012	2012+	
2000	12,145					3,739
2001	12,523					3,858
2002	12,719					3,918
2003	13,009					4,009
2004	13,289					4,096
2005	13,571					4,184
2006	13,839					4,268
2007	14,109					4,352
Jan-May '08	14,364					4,431
Jun-Dec '08	15,006	2,251		3,293		4,431
2009	15,274	3,892		5,775		4,511
2010	15,543	3,927		5,905		4,591
2011	15,844	3,981		6,035		4,682
Jan-May '12	16,107	1,671		2,569		4,760
Jun-Dec '12	16,107		2,343		4,280	4,760
2013	16,372		4,043		7,493	4,836
2014	16,631		4,071		7,648	4,912
2015	16,896		4,102		7,804	4,991
2016	17,177		4,145		7,958	5,074
2017	17,445		4,179		8,112	5,154
2018	17,711		4,213		8,266	5,233
2019	17,980		4,248		8,420	5,312
2020	18,241		4,278		8,574	5,389
2021	18,521		4,321		8,728	5,472
2022	18,802		4,363		8,882	5,556
2023	19,083		4,407		9,036	5,640
2024	19,365		4,451		9,191	5,723
2025	19,648		4,495		9,345	5,808
2026	19,930		4,540		9,498	5,891
2027	20,213		4,586		9,651	5,976
2028	20,496		4,632		9,804	6,060
2029	20,781		4,679		9,958	6,144
2030	21,066		4,726		10,111	6,229
2031	21,351		4,773		10,264	6,314
2032	21,638		4,822		10,417	6,399
2033	21,925		4,870		10,571	6,485
2034	22,213		4,919		10,724	6,570
2035	22,502		4,969		10,877	6,656
2036	22,783		5,012		11,029	6,742

The following table summarizes the estimated volume of 500 ppm diesel fuel and 15 ppm diesel fuel affected by the Two Step Nonroad Program with the 15 ppm sulfur standard being met in 2009 (Option #2c) by each year from 2008 to 2036. The spillover of highway into the NRLM diesel pools and the total volume of NRLM diesel fuel is also presented.

Table 7.1-37 - Future nonhighway Supply volumes for the U.S. outside of California for the Nonroad Program which goes to 15 ppm in 2009 instead of 2010 (MMGallons/yr)

Totals (NR, Loc & Mar)

Year	Total Volume	Affected Volume for 500 ppm			Affected Volume for 15 ppm		Spillover Volume
		2007-2009	2009-2013	2013+	2009-2013	2013+	
2000	12,145						3,739
2001	12,523						3,858
2002	12,719						3,918
2003	13,009						4,009
2004	13,289						4,096
2005	13,571						4,184
2006	13,839						4,268
2007	14,745	5,449					4,352
2008	15,006	9,504					4,431
Jan-May '09	15,274	3,731					5,229
Jun-Dec '09	15,274		2,859		3,418		5,296
2010	15,543		4,959		5,423		5,161
2011	15,844		5,036		5,543		5,264
2012	16,107		5,089		5,663		5,355
Jan-May '13	16,366		2,141		2,409		5,444
Jun-Dec '13	16,366			2,354		4,370	5,444
2014	16,625			4,063		7,647	4,914
2015	16,890			4,095		7,803	4,993
2016	17,171			4,137		7,957	5,076
2017	17,438			4,172		8,111	5,156
2018	17,705			4,205		8,265	5,235
2019	17,973			4,240		8,419	5,314
2020	18,235			4,270		8,573	5,391
2021	18,514			4,313		8,727	5,474
2022	18,795			4,356		8,881	5,558
2023	19,076			4,399		9,035	5,642
2024	19,358			4,443		9,190	5,726
2025	19,641			4,487		9,344	5,810
2026	19,923			4,532		9,497	5,894
2027	20,205			4,578		9,650	5,978
2028	20,489			4,624		9,803	6,062
2029	20,773			4,670		9,956	6,147
2030	21,058			4,717		10,110	6,231
2031	21,344			4,765		10,263	6,316
2032	21,631			4,813		10,416	6,402
2033	21,918			4,861		10,569	6,487
2034	22,205			4,910		10,723	6,572
2035	22,494			4,960		10,876	6,658
2036	22,783			5,010		11,029	6,744

The following table summarizes the estimated volume of 500 ppm diesel fuel and 15 ppm diesel fuel affected by the Two Step Nonroad Program with locomotive and marine diesel fuel complying with the 15 ppm sulfur standard along with nonroad in 2010 (Option #4) by each year from 2008 to 2036. The spillover of highway into the NRLM diesel pools and the total volume of NRLM diesel fuel is also presented.

Table 7.1-38 Future nonhighway Supply volumes for the U.S. outside of California for the Nonroad Program which has Locomotive and Marine going to 15 ppm in 2010 along with Nonroad (MMGallons/yr)

Totals (NR, Loc & Mar)

Year	Total Volume	Affected Volume for 500 ppm			Affected Volume for 15 ppm		Spillover Volume
		2007-2010	2010-2014	2014+	2010-2014	2014+	
2000	12,145						3,739
2001	12,523						3,858
2002	12,719						3,918
2003	13,009						4,009
2004	13,289						4,096
2005	13,571						4,184
2006	13,839						4,268
2007	14,745	5,449					4,352
2008	15,006	9,504					4,431
2009	15,274	9,671					4,513
Jan-May '10	15,543	4,099					4,595
Jun-Dec '10	15,543		654		5,851		4,392
2011	15,843		1,146		10,217		4,480
2012	16,107		1,171		10,380		4,557
2013	16,366		1,196		10,538		4,632
Jan-May '14	16,625		509		4,457		4,707
Jun-Dec '14	16,625					6,952	4,707
2015	16,890					12,106	4,784
2016	17,171					12,305	4,865
2017	17,438					12,496	4,943
2018	17,705					12,685	5,020
2019	17,973					12,875	5,098
2020	18,235					13,061	5,173
2021	18,514					13,260	5,254
2022	18,795					13,459	5,336
2023	19,076					13,659	5,417
2024	19,358					13,859	5,499
2025	19,641					14,060	5,580
2026	19,923					14,261	5,662
2027	20,205					14,462	5,744
2028	20,489					14,663	5,826
2029	20,773					14,865	5,908
2030	21,058					15,068	5,990
2031	21,344					15,271	6,073
2032	21,630					15,475	6,155
2033	21,918					15,680	6,238
2034	22,205					15,884	6,321
2035	22,494					16,090	6,404
2036	22,783					16,296	6,488

7.2 Refining Costs

The most significant cost involved in providing diesel fuel which meets more stringent sulfur standards is the cost of removing the sulfur at the refinery. In this section, we describe the methodology used and present the estimated costs for refiners to:

- comply with the proposed 2007 Nonroad, Locomotive and Marine (NRLM) diesel fuel sulfur standards and the 2010 nonroad diesel fuel standards,
- comply with other NRLM diesel fuel sulfur options considered, and
- comply with the already promulgated 2006 highway diesel fuel sulfur standards (an update of a previous cost analysis).

Finally, we compare our estimated costs to those developed by others who have evaluated the refining costs of meeting tighter sulfur caps for non-highway diesel fuel.

7.2.1 Methodology

7.2.1.1 Overview

This section describes the methodology used to estimate the refining cost of reducing diesel fuel sulfur content. Costs are estimated based on three distinct desulfurization technologies: conventional hydrotreating, the Linde Iso-Therming process and the Phillips SZorb adsorption process. Conventional hydrotreating cost estimates were based on information from two vendors, while the cost estimates for the other two more advanced processes was made from information provided by the respective vendors. For all three technologies, costs are estimated for each U.S. refinery currently producing distillate fuel. Conventional hydrotreating technology was projected to be used to desulfurize distillate to meet a 500 ppm sulfur cap. A mix of primarily advanced desulfurization technologies with some conventional hydrotreating technology was projected to be used to meet the 15 ppm sulfur cap. This mix of technology varied depending on the timing of the 15 ppm sulfur standard. To meet the 500 ppm and 15 ppm sulfur cap standards, refiners are expected to have to desulfurize to 340 ppm and 7 ppm, respectively.

Refining costs were developed for revamping existing hydrotreaters which produce low sulfur diesel fuel, as well as new, grass roots desulfurization units. The lower revamped costs were primarily used when streams or parts of streams were already desulfurized (i.e., highway), while the grassroots costs applied normally for untreated streams (mostly nonroad). In both cases, costs were developed for our refinery cost model and used to estimated the desulfurization cost for each refinery in the U.S. producing distillate fuel in 2000. These refinery-specific costs consider the volume of distillate fuel produced, the composition of this distillate fuel, the location of the refinery (e.g., Gulf Coast, Rocky Mountain region, etc.). The estimated composition of each refinery's distillate included the fraction of hydrotreated and nonhydrotreated straight run distillate, light cycle oil (LCO), other cracked stocks (coker, visbreaker, thermal cracked) and hydrocracked distillate, and the cost to desulfurize each of those stocks. The cost information provided by the various vendors was used to develop the desulfurization cost for each blendstock, however, when lacking, engineering judgement was used to develop the needed specific cost estimate. The average desulfurization cost for each refinery was based on the volume-weighted average of desulfurizing each of those blendstocks. The production volumes used were those indicative of the year 2008, the first full year that the proposed NRLM diesel fuel program would be applicable.

7.2.1.2 Basic Cost Inputs for Specific Desulfurization Technologies

To obtain a comprehensive basis for estimating the cost of desufurizing diesel fuel, over the past few years we have held meetings with a large number of vendors of desulfurization technologies. These firms include: Criterion Catalyst, UOP, Akzo Nobel, Haldor Topsoe, Phillips, and Linde. We have also met with numerous refiners of diesel fuel considering the use of these technologies and reviewed the literature on this subject. The information and estimates described below represent the culmination of these efforts.

The information used in our refinery cost model for estimating the cost of meeting 500 and 15 ppm sulfur caps using conventional hydrotreating is presented first. The cost methodology for conventional hydrotreating was developed for the 2007 highway diesel fuel rulemaking. Only the final process design parameters are presented here. For a complete description of the methodology used to develop the cost estimates for conventional hydrotreating, the reader should consult the Chapter 5 of the Regulatory Impact Analysis for the 2007 highway diesel fuel rule. The few variations from the methodology described in that RIA are described below.

Next we present the methodology and resulting cost information used for developing the refinery costs for the Phillips adsorption and Linde Iso-Therming processes. In this case, we begin by presenting the estimates of the process design parameters provided by the developers of these processes. These projections are then evaluated to produce sets of process design parameters which can be used to estimate the cost of meeting 500 ppm and 15 ppm NRLM diesel fuel standards for each domestic refiner. The resulting refining cost projections are presented and discussed in Section 7.2.2.

7.2.1.2.1 Conventional Desulfurization Technology

The cost of desulfurizing diesel fuel includes the capital cost related to designing and constructing the desulfurization unit, as well as the cost of operating the unit. We were able to obtain fairly compete sets of such process design paramters from two out of the five or six licensors of conventional desulfurization technologies.[9] [10] [11] These designs addressed the production of 15 ppm diesel fuel by retrofitting existing hydrotreaters originally designed to produce 500 ppm diesel fuel, as well as building new, grass roots units. These two sets of process design parameters were also used to estimate the cost of hydrotreating high sulfur diesel fuel down to 500 ppm.

In addition to the information obtained from these two vendors, we reviewed similar information submitted to the National Petroleum Council (NPC) by Akzo Nobel, Criterion, Haldor Topsoe, UOP and IFP for its study of diesel fuel desulfurization costs and discussed them with the vendors.[12] These submissions were generally not as comprehensive as those provided by the two vendors mentioned above. In all cases, these submissions corroborated the costs from the two vendors.

All of the vendors indicated that operating pressures of no more than 900 pounds per square inch (psi) would be sufficient to produce fuel meeting a 15 ppm sulfur cap. Most of the vendors projected that 650 psi would be sufficient. Likewise, a number of refiners have indicated that pressures well below 1000 psi would be sufficient. A contractor for API has indicated that they believe that a 850 psi unit is all that is necessary meet a 15 ppm cap standard, although the contractor also stated that lower pressure units would not be sufficient. Thus, we based our estimate of capital cost on two different vendor submissions which were based on units operating at 650 and 900 psi pressure.

Based on the information obtained from the two vendors of conventional hydrotreating technologies, as well as that obtained from Phillips and Linde, we project that refiners would use conventional hydrotreating to produce NRLM diesel fuel meeting the proposed 500 ppm standard in 2007. This unit would include heat exchangers, a fired pre-heater, a reactor, a hydrogen compressor and a make up compressor, and both high pressure and low pressure strippers. The refinery would also require a source of new hydrogen, an amine scrubber and a sulfur plant. Most all refineries already have sources of hydrogen, an amine scrubber and a sulfur plant. However, considering the hydrogen demand for complying with Tier 2 sulfur standards for gasoline and the 15 ppm cap on highway diesel sulfur, no residual refinery production hydrogen is expected to exist. Thus, we project that any new hydrogen demand would likely have to be produced from natural gas, either on-site or by a third party. Likewise, modest expansions of its amine scrubber and sulfur plant would be required.

Producing diesel fuel meeting a 15 ppm standard generally requires much greater reactor volume and a larger hydrogen capacity, both in terms of compressor capacity and ability to introduce this hydrogen into the reactor, than are required to meet a 500 ppm cap. Since the 15 ppm sulfur cap for nonroad diesel fuel would follow the 500 ppm NRLM sulfur cap by only three years, we project that refiners would have designed any new hydrotreaters built in 2007 to be easily retrofitted with additional equipment, such as a second reactor, a hydrogen compressor, a recycle scrubber, an inter-stage stripper and other associated process hardware. The technical approach described by each vendor to achieve a 15 ppm diesel fuel sulfur cap (average level of 7-8 ppm) is summarized in Table 7.2-1.

Table 7.2-1
Modifications Necessary to Reduce 500 ppm Sulfur Levels to 15 ppm

Diesel Fuel Sulfur Level	Vendor A	Vendor B
7-8 ppm (15 ppm cap)	Change to a more active catalyst Install recycle gas scrubber Modify compressor Install a second reactor, high pressure (900 psi) Use existing hot oil separator for inter-stage stripper	Change to a more active catalyst Install a recycle gas scrubber Install a second reactor (650 psi) Install a color reactor Install an interstage stripper

The vendors assumed that the existing highway desulfurization unit in place could be utilized (revamped) to comply with the 15 ppm sulfur standards. This includes a number of hydrotreater sub-units which are necessary for desulfurization and would save on both capital and operating costs for a two stage revamp compared to whole new grassroots unit. These sub-units include heat exchangers, a heater, a reactor filled with catalyst, two or more vessels used for separating hydrogen and any light ends produced by cracking during the desulfurization process, a compressor, and sometimes a hydrogen recycle gas scrubber. The desulfurization subunits listed here are discussed in detail in the feasibility section contained in Chapter 5.

In order to estimate the cost of meeting the proposed NRLM diesel fuel sulfur standards, it was necessary to evaluate three situations which would be faced by refiners: 1) producing NRLM diesel fuel meeting a 15 ppm cap from diesel fuel already being hydrotreated to meet a 500 ppm cap (i.e., a highway revamp), 2) producing NRLM diesel fuel meeting a 15 ppm cap from high sulfur distillate (i.e., grass roots 15 ppm hydrotreater), and 3) producing NRLM diesel fuel meeting a 500 ppm cap from high sulfur distillate (i.e., grass roots 500 ppm hydrotreater). Sets of process design parameters for the first two of these desulfurization configurations were developed for the highway rule. As discussed above, only the results of the previous derivations are presented below. The third configuration was not addressed for the highway diesel fuel rule, as highway diesel fuel was already meeting a 500 ppm cap. The section which develops the process design parameters for this third configuration includes a short description of the methodology used in its development, as it is very similar to those used to develop the first two sets of process design parameters.

One straightforward adjustment was made to all the capital costs developed for the 2007 highway diesel fuel rule. The capital costs developed for that rule were in terms of 1999 dollars. These costs were increased by 2.5% to reflect construction costs in 2002 dollars.[13]

7.2.1.2.1.2 Revamping to Process 500 ppm Diesel Fuel to Meet a 15 ppm Cap

These process design projections developed in this section would apply to a revamp of an existing desulfurization unit with additional hardware to enable the combined older and new unit to meet a 15 ppm sulfur cap. The portion of these projections which apply to operating costs are also relevant if a refiner would decide to replace their existing diesel fuel desulfurization unit with a new grassroots unit. In this case, the entire capital cost of the grass roots unit would be incurred. However, the incremental operating costs would be those of the new grass roots unit less those of the existing hydrotreater (which are developed in this section).

The process design parameters shown below were taken directly from those shown in the RIA for the 2007 highway diesel fuel rule, with one adjustment. Diesel fuel complying with the current 500 ppm sulfur standard typically contains 340 ppm sulfur. We expect refiners complying with the proposed 500 ppm NRLM diesel fuel sulfur cap would also desulfurize down to roughly 340 ppm sulfur. Thus, in revamping an existing 500 ppm hydrotreater to comply with a 15 ppm cap, refiners would have to desulfurize from 340 ppm down to 7 ppm. This is analogous to what we assumed in the analysis for the 2007 highway diesel fuel rule.

However, after the highway diesel fuel rule was finalized, it became evident that the vendor projections assumed a starting sulfur level of 500 ppm and not 340 ppm. Thus, the vendor projections assumed more desulfurization would be needed than is the case here. Based on a curve of hydrogen consumption versus initial and final sulfur level, developed in the Draft RIA to the 2007 highway diesel fuel rule, reducing the initial sulfur level from 500 ppm to 340 ppm reduces hydrogen consumption by 3.5%. We assumed that all cost-related parameters (capital cost, catalyst cost, yield losses, and utilities) would be reduced by the same 3.5%.

Table 7.2-6 presents the process design parameters for desulfurizing 500 ppm sulfur diesel fuel to meet a 15 ppm cap standard.[B]

[B] There are no tables numbered 7.2-2 through 7.2-5.

Table 7.2-6
Process Projections for Revamping an Existing Diesel Fuel Hydrotreater Desulfurizing Diesel Fuel Blendstocks from 500 ppm Cap to 15 ppm Cap

	Straight Run	Other Cracked Stocks	Light Cycle Oil
Capacity (BPSD)	25,000	25,000	25,000
Capital Cost (ISBL) ($million)	16	19	22
Liquid Hour Space Velocity (hr^{-1})	1.25	0.7	0.6
Hydrogen Consumption (scf/bbl)	93	223	362
Electricity (kW-hr/bbl)	0.4	0.7	0.8
HP Steam (lb/bbl)	-	-	-
Fuel Gas (BTU/bbl)	40	70	80
Catalyst Cost ($/BPSD)	0.2	0.4	0.5
Yield Loss (wt%)			
Diesel	1.0	1.9	2.1
Naphtha	-0.7	-1.3	-1.4
LPG	-0.04	-0.07	-0.08
Fuel Gas	-0.04	-0.11	-0.13

7.2.1.2.1.3 Process Design Projections for a Grassroots Unit Producing 15 ppm Fuel

The process design parameters presented in this section were taken directly from those derived in the RIA for the 2007 highway diesel fuel rule. These costs would apply primarily to refineries only producing, or predominantly producing, high sulfur diesel fuel today. In addition, the capital cost portion of these costs would apply to a a refinery which replaced an existing hydrotreater with a grassroots unit instead of revamping their existing hydrotreater. In this case, these refiners would incur the capital costs outlined here, but their operating costs would be based on a revamp as described above. Most refineries which currently produce high sulfur distillate fuel also produce some highway diesel fuel. In this case, we project costs which reflect those of a revamp and a grass roots unit. The methodology for this merging of the two costs is described in Section 7.2.1.5 below.

Table 7.2-7 presents the process design parameters for desulfurizing high sulfur distillate fuel to meet a 15 ppm cap standard in a grassroots unit.

Table 7.2-7
Process Projections for Installing a New Grassroots Unit for Desulfurizing Untreated Distillate Fuel Blendstocks to Meet a 15 ppm Cap Standard

	Straight Run	Other Cracked Stocks	Light Cycle Oil
Capacity BPSD (bbl/day)	25,000	25,000	25,000
Capital Cost (ISBL) (MM$)	31	37	42
Liquid Hour Space Velocity (Hr^{-1})	0.8	0.5	0.4
Hydrogen Consumption (SCF/bbl)	240	850	1100
Electricity (KwH/bbl)	0.6	1.1	1.2
HP Steam (Lb/bbl)	-	-	-
Fuel Gas (BTU/bbl)	60	105	120
Catalyst Cost ($/BPSD)	0.3	0.6	0.8
Yield Loss (%)			
Diesel	1.5	2.9	3.3
Naphtha	1.1	2.0	2.3
LPG	0.06	0.11	0.12
Fuel Gas	0.06	0.17	0.20

Unlike processing highway diesel fuel which is assumed to contain 340 ppm sulfur, the sulfur content of high sulfur distillate fuel can vary dramatically from refiner to refiner and region to region. A adjustment in hydrogen consumption was made for differing starting sulfur levels. The basis for the amount of sulfur needed to be removed is that the starting feed, comprised of 69 percent straight run, 23 percent LCO and 8 percent cracked stocks, contains 9000 ppm sulfur (0.9 weight percent). However, as described below in Subsection 7.2.1.3, the average concentration of sulfur in the overall distillate pool, and especially that part of the pool which is untreated, varies by PADD. After estimating what this sulfur level is, we adjusted the hydrogen consumption for this varying sulfur level (According to Vendor B, removing sulfur from diesel fuel consumes 125 scf/bbl for each weight percent of sulfur removed.[14]) We did not adjust the hydrogen consumption for the other qualities, polyaromatics and olefins, because we do not believe that these would likely vary independently with the sulfur level. Since the removal of sulfur consumes less than half the estimated hydrogen consumed as untreated 9000 ppm is desulfurized to 15 ppm, the adjustment is always less than 50 percent. The adjustment is applied as an adjustment ratio to each untreated blendstock type for a refinery with a distillate hydrotreater. The adjustment ranged from 0.79 for PADD 5, which has an estimated untreated distillate sulfur level of 2610 ppm, to 1.1 for PADD 3 which has an estimated untreated distillate sulfur level of 11,320 ppm. No adjustment was necessary for the already hydrotreated part of the distillate pool since this subpool is always assumed to contain 340 ppm sulfur.

For refineries without a distillate hydrotreater, our adjustment to account for differing starting sulfur levels assumes that they currently blend only unhydrotreated blendstocks into the distillate which comprises the high sulfur pool. Thus, we are making our adjustments based on a lower starting sulfur level. Our adjustment for these refineries ranged from 0.79 for PADD 5, which has an estimated untreated sulfur level of 2540 ppm, to 0.87 for PADD 3 which has a starting sulfur level of 5200 ppm, for these refineries without a distillate hydrotreater. The various hydrogen consumption adjustment values are summarized in Table 7.2-8.[C]

Table 7.2-8
Hydrogen Consumption Adjustment Factors: Revamped Units

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Refinery with Distillate HT	0.90	0.88	1.1	0.84	0.79
No Distillate HT	0.81	0.80	0.87	0.79	0.79

7.2.1.2.1.4 Desulfurizing High Sulfur Distillate Fuel to a 500 ppm Cap

Finally, we needed to provide inputs for our cost model for desulfurizing untreated, high sulfur distillate to meet a 500 ppm sulfur cap standard, which is the first step of our two step program. These inputs are estimated by simply subtracting the inputs for the revamped unit for desulfurizing 500 ppm diesel fuel down to 15 ppm from the inputs for a grassroots unit for desulfurizing untreated diesel fuel down to 15 ppm. The untreated to 500 ppm inputs for our refinery cost model are summarized in Table 7.2-10.

[C] There is no table numbered 7.2-9.

Table 7.2-10
Process Projections for Installing a New Unit for Desulfurizing
Untreated Diesel Fuel Blendstocks to Meet a 500 ppm Sulfur Cap Standard

	Straight Run	Coker Distillate	Light Cycle Oil
Capacity BPSD (bbl/day)	25,000	25,000	25,000
Capital Cost (ISBL) (MM$)	16	19	21
Liquid Hour Space Velocity (Hr^{-1})	2.4	1.9	1.3
Hydrogen Consumption (SCF/bbl)	147	628	738
Electricity (KwH/bbl)	0.2	0.4	0.4
HP Steam (Lb/bbl)	-	-	-
Fuel Gas (BTU/bbl)	21	37	43
Catalyst Cost ($/BPSD)	0.1	0.2	0.3
Yield Loss (%)			
Diesel	0.5	1.1	1.2
Naphtha	-0.4	-0.7	-0.85
LPG	-0.02	-0.04	-0.04
Fuel Gas	-0.02	-0.06	-0.07

Again, a hydrogen consumption adjustment was made for starting sulfur levels which differ from 9000 ppm. In this case, the hydrogen adjustment ended up being larger than the grassroots desulfurization unit as the adjustment to the hydrogen consumption for going from untreated to 500 ppm comprises a larger percentage of the total hydrogen consumption. The adjustment is applied as an adjustment ratio to each blendstock type and it ranged from 0.67 for PADD 5, which has an estimated untreated distillate sulfur level of 2610 ppm, to 1.12 for PADD 3 which has an estimated untreated distillate sulfur level of 11,320 ppm. No adjustment was necessary for the already hydrotreated part of the distillate pool since this subpool is always assumed to contain 340 ppm sulfur.

For refineries without a distillate hydrotreater, our analysis does not assume that they currently hydrotreat any of the distillate which comprises the high sulfur pool. Thus, we estimate a starting sulfur level which is somewhat lower. Our adjustment for these refineries ranged from 0.67 for PADD 5, which has an estimated untreated sulfur level of 2540 ppm, to 0.80 for PADD 3 which has a starting sulfur level of 5200 ppm. The various hydrogen consumption adjustment values are summarized in Table 7.2-11.

Table 7.2-11
Hydrogen Consumption Adjustment Factors: Revamped Units

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Refinery with Distillate HT	0.85	0.82	1.1	0.75	0.67
No Distillate HT	0.71	0.69	0.80	0.68	0.67

7.2.1.2.1.5 Hydrocrackate Processing and Tankage Costs

We believe that refineries with hydrocrackers will have to invest some capital and incur some operating costs to ensure that recombination reactions at the exit of the second stage of their hydrocracker do not cause the diesel fuel being produced by their hydrocracker to exceed the cap standard. The hydrocracker is a very severe hydrotreating unit capable of hydrotreating its product from thousands of ppm sulfur to essentially zero ppm sulfur, however, hydrogen sulfide recombination reactions which occur at the end of the cracking stage, and fluctuations in unit operations, such as temperature and catalyst life, can result in the hydrocracker diesel product having up to 30 ppm sulfur in its product stream.[15] [16] Thus, refiners may need to install a finishing reactor for the diesel stream produced by the hydrocracker. According to vendors, this finishing reactor is a low temperature, low pressure hydrotreater which can desulfurize the simple sulfur compounds which are formed in the cracking stage of the hydrocracker.

Additionally, since the 15 ppm diesel sulfur standard is a very stringent cap standard, we are taking into account tankage that would likely be needed. We believe that refiners could store high sulfur batches of highway diesel fuel or nonroad diesel fuel during a shutdown of the diesel fuel hydrotreater. Diesel fuel production would cease in the short term, but the rest of the refinery could remain operative. To account for this, we provided for the cost in our cost model of the installation of a tank that would store 10 days of 15 ppm sulfur diesel production sufficient for a 10 day emergency turnaround which is typical for the industry, which would be about 3 million dollars for a 270,000 barrel storage tank.[17] This amount of storage should be adequate for most unanticipated turnarounds. We presumed that each refinery would need to add such storage, (for some refineries, off-spec diesel fuel could also be sold as high sulfur heating oil or fuel oil).

The cost inputs for the storage tank and the finishing reactor are summarized in Table 7.2-12.

Table 7.2-12
Process Operations Information for Additional
Units used in the Desulfurization Cost Analysis

	Diesel Storage Tank	Distillate Hydrocracker Post Treat Reactor
Capacity	50,000 bbls	25,000 (bbl/day)
Capital Cost (MM$)	0.75	5.7[18]
Electricity (KwH/bbl	—	0.98
HP Steam (Lb/bbl)	—	4.2
Fuel Gas (BTU/bbl)	—	18
Cooling Water (Gal/bbl)	—	5
Operating Cost ($/bbl)	none[a]	—

[a] No operating costs are estimated directly, however both the ISBL to OSBL factor and the capital contingency factor used for desulfurization processes is used for the tankage as well, which we believe to be excessive for storage tanks so it is presumed to cover the operating cost.

Refiners will also likely invest in a diesel fuel sulfur analyzer.[19] The availability of a sulfur analyzer at the refinery would provide essentially real-time information regarding the sulfur levels of important streams in the refinery and facilitate operational modifications to prevent excursions above the sulfur cap. Based on information from a manufacturer of such an analyzer, the cost for a diesel fuel sulfur analyzer would be about $50,000, and the installation cost would be another $5000.[20] Compared to the capital and operating cost of desulfurizing diesel fuel, the cost for this instrumentation is far below 1 percent of the total cost of this program. Because the cost is so small, the cost of an analyzer was covered as a cost contingency described in Subsection 7.2.1.4.1.

7.2.1.2.2. Sulfur Adsorption - Phillips SZorb

Phillips has developed a desulfurization technology applicable to either gasoline or diesel fuel, as discussed in some detail in Chapter 5. At our request, Phillips provided process design parameters for an SZorb diesel fuel desulfurization unit processing seven different feedstock compositions. Table 7.2-13 summarizes the information provided.[21,22]

Table 7.2-13
SZorb Process Design Parameters

Diesel Fuel Composition	Diesel A	Diesel B	Diesel C	Diesel D	Diesel E	Diesel F	Diesel G
	HT: 80% SR & 20% LCO[a]	83% SR & 17% HT LCO	SR, CKR & HT & nonHT LCO	nonHT SR	nonHT LCO	Diesel B with some non-hwy	Diesel F with HT shutdown
Feed Sulfur (ppm)	523	460	662	2000	2400	1800	3300
Product Sulfur (ppm)	6	<1	9	<1	10	6	4
LHSV (hr^{-1})	2	2	2	6	1	1.5	1
H_2 Chemical Consumption	-5	-15	15	42	186	2	90
Feed API Gravity	33	36	—	41	20	—	—
Feed 10%	440	402	—	318	480	—	—
Feed 50%	513	492	—	401	537	—	—
Feed 90%	604	573	—	496	611	—	—

[a] HT = hydrotreated, nonHT = non-hydrotreated, SR = straight run, CKR = light coker gas oil

Diesel fuels A, B and C are somewhat representative of highway diesel fuel, although the sulfur level is slightly higher than the average highway diesel fuel sulfur level found in the U.S. Diesel fuel A is a hydrotreated blend of 80 percent straight run and 20 percent LCO with distillation properties typical of today's highway diesel fuel. Diesel fuel B is a lighter blend than diesel fuel A with 83 percent unhydrotreated straight run and 17 percent hydrotreated LCO. Diesel fuel C is a rather typical diesel fuel composition for a refinery with an FCC unit and a coker. The distillation qualities of this diesel fuel, and those of diesel fuels F and G are not known.

Diesel fuels D, E, F and G have moderate sulfur levels more typical of non-highway distillate fuels. However, these fuels' sulfur contents are not as high as most refiners' unhydrotreated distillate, as discussed above. Diesel fuel D is comprised of unhydrotreated straight run with distillation qualities lighter than the average diesel fuel. Diesel fuel E is 100% unhydrotreated LCO although its relatively low sulfur level suggests that it is either from a sweet crude refinery or from a refinery with a FCC feed hydrotreater. Its distillation curve is typical of the LCO blended into the diesel fuel pool. Diesel fuel F consists of diesel fuel B plus some amount of non-highway diesel fuel. The composition of the non-highway diesel fuel is unknown. However, if we assume that the non-highway diesel fuel contains the national average sulfur level of 3400 ppm, the sulfur level of this diesel fuel blend suggests that it may be about half non-highway and half diesel fuel B. However, if the sulfur content is closer to the maximum 5000 ppm allowed under ASTM specifications, then diesel fuel F might only contain 25-30% non-highway diesel fuel. Diesel fuel G consists of diesel fuel F with the highway hydrotreater shutdown. The highway hydrotreater appears to have been only hydrotreating the LCO fraction of diesel fuel B, which represents less than 17% of Diesel fuel G. Since the sulfur content of diesel fuel G exceeds that of diesel fuel F by 1500 ppm, the sulfur content of the unhydrotreated LCO in diesel fuel B must be 9000 ppm or more, which is typical.

The design parameters provided by Phillips involve a stand-alone SZorb unit, sometimes processing unhydrotreated feedstock, and sometimes processing partially hydrotreated feedstock (i.e., following an existing conventional hydrotreater). In all cases, sulfur content is being reduced to 10 ppm or less, very close to the 7-8 ppm target which we expect refiners to have to achieve on average to comply with a 15 ppm cap. Below, we will use the process design parameters shown in Table 7.2-13 to project the cost of an SZorb unit performing two different tasks: 1) processing current high sulfur distillate to meet a 15 ppm cap, and 2) processing 500 ppm NRLM diesel fuel to meet a 15 ppm cap. The methodology used to develop the projected costs for these two tasks are presented below. As was done for conventional hydrotreating, we will develop cost estimates for processing three individual blendstocks: straight run, LCO and light coker gas oil, in order to be able to project desulfurization costs for individual refineries whose diesel fuel compositions vary dramatically.

7.2.1.2.2.1 Desulfurizing High Sulfur Distillate Fuel to Meet a 15 ppm Sulfur Cap

Phillips provided four sets of process design parameters for using SZorb to achieve a 15 ppm cap from high sulfur distillate. Two of these designs treated a pure blendstock, straight run and LCO. However, neither blendstock had properties typical of these blendstocks for the average refinery. Thus, the four sets of process designs have to evaluated together to develop sets of process design parameters for the three distillate blendstocks.

Also, the maximum initial sulfur level shown in Table 7.2-13 is 3300 ppm sulfur. Thus, we believe that it is reasonable to limit the applicability of our projections to feedstocks containing 3300 ppm sulfur or less. Current high sulfur distillate averages 3400 ppm sulfur. Therefore, it is reasonable to expect that just under half of all NRLM diesel fuel contains 3300 ppm sulfur or less.

We have broken down the derivation of the cost of a stand-alone SZorb unit capable of producing 15 ppm diesel fuel into four parts: hydrogen consumption, utilities and yield losses, catalyst cost and capital cost.

Hydrogen Consumption: Phillips provided an estimate of hydrogen consumption for two individual blendstocks, straight run and LCO. Diesel fuel D was an unhydrotreated straight run stream hydrotreated to less than 1 ppm sulfur. Doing so consumed 42 scf/bbl of feed. Comparing its sulfur content to those for typical high sulfur distillate from Chapter 5.1, it contains 90% of the amount of sulfur in average unhydrotreated straight run. However, its distillation properties show this stream to be lighter than the average straight run feedstock. Thus, the hydrogen consumption for a more typical could be slightly higher, due to the greater concentration of aromatics typical for heavier cuts of distillate.

Interestingly, the hydrogen consumption for a number of the diesel fuel feedstocks including some LCO shown in Table 7.2-13 is less than 42 scf/bbl. A couple even show a net production of hydrogen. One of the aspects of the SZorb process is that the temperature can be varied to control the level of aromatics saturation. At low temperatures, aromatics content can actually be increased, generating hydrogen. However, there is a practical limit to this, as higher aromatic contents reduce cetane. This flexibility of the SZorb process makes it difficult to accurately predict typical hydrogen consumption, as each refiner's ability to absorb a loss in cetane will differ. Thus, to be conservative, we assumed that the 42 scf/bbl hydrogen consumption of diesel fuel D was representative of treating typical straight run.

The LCO feed (diesel fuel E) contains 2400 ppm sulfur, which is about two-thirds of the average amount of sulfur in unhydrotreated LCO, which contains 3500 ppm sulfur, as discussed in Chapter 5.1. However, it was desulfurized to a lower sulfur level than what would be expected for meeting the 500 ppm sulfur target (typically around 340 ppm). LCO usually comprises about 25 percent of diesel fuel for the average refinery with an FCC unit. LCO will likely contribute the most amount of sulfur after hydrotreating, because it generally contains largest concentration of sterically hindered sulfur compounds. Thus, to meet a 7-8 ppm sulfur target, LCO will likely need to be desulfurized to about 20 ppm and contribute about 5 ppm to the diesel fuel pool. Coker distillate might be desulfurized to roughly 5 ppm and straight run to 1-2 ppm, resulting in an average diesel fuel sulfur level of about 7 ppm. Therefore, the hydrogen consumption of 186 scf/bbl is lower than that for average LCO due to its low initial sulfur level, but is high (for a 7-8 ppm target), due to its final sulfur level of 10 ppm. Lacking the ability to compensate for either of these two factors, we assumed that the hydrogen consumption of 186 scf/bbl for diesel fuel E was representative of the hydrogen consumption for average LCO.

Phillips did not provide an estimate of the hydrogen consumption for treating 100% coker distillate. Therefore, we assumed that the relationship for hydrogen consumption for straight run, light coker distillate and LCO being treated by an SZorb unit would be the same as that for conventional hydrotreating. As described in Table 7.2-7, the hydrogen consumptions for conventionally hydrotreating straight run, coker distillate and LCO to 15 ppm are estimated to be 240, 850 and 1100 scf/bbl. Thus, for conventional hydrotreating, the hydrogen consumption for coker distillate falls 70 percent of the way between straight run and LCO. Thus, if we apply this same percentage to the straight run and LCO hydrogen consumption values for SZorb, we estimate that coker distillate would consume 144 scf/bbl of hydrogen.

An adjustment to these hydrogen consumptions was developed to account for differences in initial sulfur levels. The Phillips' feedstocks upon which the above hydrogen consumption estimates were based contain about 2100 ppm sulfur. However, as described below in subsection 7.2.1.3, the average concentration of sulfur in the overall distillate pool, and especially that part of the pool which is untreated, exceed 2100 ppm sulfur. To account for the additional hydrogen which would be consumed when processing higher sulfur feeds, we increased hydrogen consumption by 12.5 scf/bbl for each 1000 ppm of additional initial sulfur content. We did not adjust hydrogen consumption for other feedstock qualities, such as polyaromatics and olefins, because we do not believe that these would likely vary consistently with the sulfur level.

Combination with sulfur represents a significant portion of total hydrogen consumption for the Phillips process. The sulfur levels of the feeds reported by Phillips are significantly lower than the average initial sulfur levels in each PADD. Thus, the adjustments are always greater than 1.0.

For refineries with a distillate hydrotreater, the adjustment factor ranged from 1.1 for PADD 5, which has an estimated untreated distillate sulfur level of 2610 ppm, to 2.4 for PADD 3, which has an estimated untreated distillate sulfur level of 11,320 ppm. No adjustment is necessary for the already hydrotreated part of the distillate pool. This sub-pool is always assumed to contain 340 ppm sulfur, for which we use the hydrogen consumptions developed in the next section which evaluates adding SZorb unit after a hydrotreater producing 500 ppm diesel fuel.

For refineries without a distillate hydrotreater, they have no hydrotreated blendstocks, but still meet applicable sulfur limits. Thus, we estimate lower initial sulfur levels than those mentioned above. Our adjustment factors for these refineries ranged from 1.1 for PADD 5, which has an estimated initial sulfur level of 2540 ppm, to 1.5 for PADD 3 which has a initial sulfur level of 5200 ppm. The various hydrogen adjustment factors for refineries with and without a hydrotreater are summarized in the following table:

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
with Dist HT	1.6	1.5	2.4	1.3	1.1
no Dist HT	1.2	1.1	1.5	1.1	1.1

Utilities and Yield Losses: Phillips did not provide specific estimates of the utility demands for the seven designs shown in Table 7.2-13. Thus, we estimated utility demands based on a comparison of SZorb to conventional hydrotreating, guided by some general estimates provided by Phillips. The largest consumer of electricity in conventional hydrotreating is the hydrogen compressor. The SZorb process differs, in that the absorption catalyst must be recycled between the reactor and the regeneration reactor. While the SZorb process consumes much less hydrogen, it operates like conventional hydrotreating in that it requires an excess amount of hydrogen to be mixed with the diesel fuel. Thus, the total amount of hydrogen being compressed is roughly the same. However, the SZorb process operates at 275-500 psi, which is about half of the pressure at which conventional desulfurization operates. Although the SZorb process operates at about half the pressure of conventional hydrotreating and demands less hydrogen, the need to recycle catalyst likely offsets some of the savings related to hydrogen compression. Still, we estimated that the electrical demand for SZorb would be one half that of conventional hydrotreating shown in Table 7.2-7. Thus, we estimate SZorb’s electricity demand to be 0.3, 0.55, and 0.6 kW-hr/bbl for straight run, light coker gas oil, and LCO, respectively.

Concerning fuel gas, it is used to heat up the feed to enable the desulfurization reaction to occur. The SZorb process operates at about the same temperature as conventional hydrotreating. Thus, we assumed that fuel gas demand would be the same as conventional hydrotreating listed in Table 7.2-7, or 60, 105, and 120 btu/bbl for straight run, light coker gas oil, and LCO, respectively.

Due to its use of adsorption, instead of hydrogenation, SZorb essentially has no yield losses.

Catalyst Costs: Conversations with Phillips indicated that the catalyst is likely to be cheaper than conventional hydrotreating catalysts. However a significant level of catalyst demand would have to occur to realize economies of scale for this lower cost to be realized. Since this process is just emerging and not many units have been licensed yet, we decided to assume the same catalyst cost as for conventional hydrotreating (shown in Table 7.2-7), or 0.3, 0.6, and 0.8 $/BPSD for straight run, light coker gas oil, and LCO, respectively.

Capital Costs: In their literature, Phillips only provides capital cost estimates for an SZorb unit processing 500 ppm sulfur diesel fuel to meet a 15 ppm sulfur cap. To be conservative[d], we assumed that the ratio of the capital costs of SZorb units treating high sulfur and 500 ppm diesel fuel to meet a 15 ppm cap, would be the same as the ratio of the capital costs of conventional hydrotreaters doing the same thing. This ratio is a factor of two for conventional hydrotreating. Phillips estimates that an SZorb unit reducing sulfur content from 500 ppm to 15 ppm would be $48 million for a 40,000 bbl/day unit, fully installed on the Gulf Coast. Thus, the cost of an SZorb unit treating the same volume of high sulfur distillate would be $96 million.

A number of steps still needed to be performed before this cost could be converted to a capital cost for processing the three individual diesel fuel blendstocks on a basis comparable to those for conventional hydrotreating above. First, we assumed that this cost included some provision for off-site costs, while the primary capital costs estimates, such as those shown in Tables 7.2-6 and 7.2-7 for conventional hydrotreating, only include “inside battery limit” (ISBL) costs. Thus, we divided the $96 million cost by a factor of 1.2 (from Table 7.2-23 below) to remove off-site costs. This produced an ISBL cost of $80 million. We then scaled this ISBL cost down to represent that for a 25,000 bbl/day unit using the “six-tenths rule with an exponent of 0.65. The scaling factor representing this reduction in volumetric capacity is 0.74 ($(25{,}000 / 40{,}000)^{0.65}$). Multiplying the $80 million cost by this factor produced a revised cost of $59 million for a 25,000 bbl/day unit.

The final step was to convert this cost for processing a mix of blendstocks to those for processing individual blendstocks. We assumed that this unit was designed to process a typical diesel fuel comprised of 69% straight run, 23% LCO and 8% other cracked stocks. We also assumed that the relationship between the capital costs for specific blendstocks (straight run, coker distillate and LCO) for SZorb was the same as those for conventional hydrotreating. Using the capital costs for conventional hydrotreating of $31, $37 and $42 million for straight run, coker distillate and LCO from Table 7.2-7, the capital cost for the above average feed

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[D] The assumption is likely conservative because the SZorb desulfurization process is likely able to handle higher sulfur levels partially or perhaps even primarily by a higher rate of catalyst recycle as opposed to just increasing the unit size.

composition would be $34 million. Thus, the capital cost for an SZorb unit would be 1.7 times higher (59/34). Multiplying the capital costs for processing the individual blendstocks using conventional hydrotreating by 1.73 produced SZorb capital costs of $53, $63 and $72 million for straight run, coker distillate and LCO average.

Summary of Process Design Parameters: The process design parameters for a new, 25,000 bbl/day SZorb unit are summarized in Table 7.2-14.

Table 7.2-14
Process Design Parameters for a New SZorb Unit Desulfurizing High Sulfur Distillate Fuel to Meet a 15 ppm Cap Standard

	Straight Run	Other Cracked Stocks	Light Cycle Oil (LCO)
Capital Cost ($million)	52	63	71
Unit Size (BPSD)	25,000	25,000	25,000
Hydrogen Demand (scf/bbl)	42	144	186
Electricity Demand (kW-hr/bbl)	0.3	0.55	0.6
Fuel Gas Demand (btu/bbl)	60	105	120
Catalyst Cost ($/BPSD)	0.3	0.6	0.8
Yield Loss	0	0	0

7.2.1.2.2.2 Desulfurizing 500 ppm Diesel Fuel to Meet a 15 ppm Cap

We next estimated the process design parameters for an SZorb unit which treats distillate which has already been hydrotreated to meet a 500 ppm cap down to 7-8 ppm. We assume that this feed contains 340 ppm sulfur, the average sulfur content of highway diesel fuel today outside of California.

Phillips provided three sets of process design parameters for using SZorb to achieve a 15 ppm cap from distillate with sulfur contents just above 340 ppm (diesel fuels A, B, and C). None of these designs treated a pure blendstock. Thus, the three sets of process designs have to evaluated together to develop sets of process design parameters for the three distillate blendstocks.

As we did above, we have broken down the derivation of the cost of an SZorb unit capable of producing 15 ppm diesel fuel from 500 ppm diesel fuel into four parts: hydrogen consumption, utilities and yield losses, catalyst cost and capital cost.

Hydrogen Consumption: In order to estimate the hydrogen consumption for each blendstock type, we focused on diesel fuel A, which is an 80/20 blend of straight run and LCO. This fuel is the closest to the composition of average diesel fuel of diesel fuels A, B, and C shown in Table 7.2-13. Processing diesel fuel A to 6 ppm sulfur actually produces 5 scf/bbl of hydrogen. We assumed that processing straight run would produce 10 scf/bbl of hydrogen, while processing LCO would consume 15 scf/bbl. An 80/20 weighting of these two figures produces a net hydrogen production of 5 scf/bbl, precisely that for diesel fuel A. We again based the hydrogen consumption for processing coker distillate on its relative hydrogen consumption when using conventional hydrotreating. There, the hydrogen consumption to process coker distillate falls 70% of the way between those for straight run and LCO. Here, 70% of the way between -5 and +10 is +5. Thus, we assumed that the hydrogen consumption for coker distillate would be 5 scf/bbl.

Utilities and Yield Losses: As we assumed for an SZorb unit processing high sulfur distillate, we assumed that electricity demand for an SZorb unit processing 500 ppm diesel fuel would be half that for conventional hydrotreating (shown in Table 7.2-6), or 0.19, 0.34, and 0.39 kW-hr/bbl for straight run, light coker gas oil, and LCO, respectively.

Concerning fuel gas, as we assumed for an SZorb unit processing high sulfur distillate, we assumed that fuel gas demand for an SZorb unit processing 500 ppm diesel fuel would be the same catalyst cost as for conventional hydrotreating (shown in Table 7.2-6), or 38, 68, and 77 btu/bbl for straight run, light coker gas oil, and LCO, respectively.

Due to its use of adsorption, instead of hydrogenation, SZorb essentially has no yield losses.

Catalyst Costs: As we assumed for an SZorb unit processing high sulfur distillate, we assumed that the catalyst costs for an SZorb unit processing 500 ppm diesel fuel would be the same catalyst cost as for conventional hydrotreating (shown in Table 7.2-6), or 0.1, 0.2, and 0.24 $/BPSD for straight run, light coker gas oil, and LCO, respectively.

Capital Costs: As mentioned above, Phillips estimates that an SZorb unit reducing sulfur content from 500 ppm to 15 ppm would be $48 million for a 40,000 bbl/day unit installed on the Gulf Coast, including off-site costs. We divided by a factor of 1.2 to remove off-sites for a new unit (see Table 7.2-23), producing an ISBL cost of $40 million. We scaled this cost down to represent that of a 25,000 bbl/day unit using the “six-tenths rule with an exponent of 0.65. This produced a scaling factor of 0.74 and a revised ISBL cost of $29 million. As we did above, we assumed that this unit was designed to process a typical diesel fuel comprised of 69% straight run, 23% LCO and 8% other cracked stocks. We again assumed that the relationship between the capital costs for specific blendstocks (straight run, coker distillate and LCO) for SZorb was the same as those for conventional hydrotreating.

Using the capital costs for conventional hydrotreating of $15, $18 and $21 million for straight run, coker distillate and LCO from Table 7.2-7, the capital cost for the above average feed composition would be $17 million. Thus, the capital cost for an SZorb unit would be 1.7 times higher, or $27, $32 and $37 million for straight run, coker distillate and LCO average.

Summary of Process Design Parameters: The process design parameters for a new, 25,000 bbl/day SZorb unit are summarized in Table 7.2-15.

Table 7.2-15
Process Design Parameters for an SZorb Unit Desulfurizing 500 ppm
Distillate Fuel to Meet a 15 ppm Cap Standard
Blendstocks from 500 ppm to 15 ppm

	Straight Run (SR)	Other Cracked Stocks	Light Cycle Oil (LCO)
Capital Cost ($MM)	27	32	37
Unit Size (bbl/stream Day)	25,000	25,000	25,000
Hydrogen Demand (scf/bbl)	-10	8	15
Electricity Demand (kwh/bbl)	0.19	0.34	0.39
Fuel Gas Demand (btu/bbl)	39	68	77
Catalyst Cost ($/bpsd)	0.1	0.19	0.24
Yield Loss	0	0	0

7.2.1.2.3 Linde Isotherming

Linde has licensed a technology called IsoTherming which is designed to desulfurize both highway and non-highway distillate fuel. Upon our request, Linde provided basic design parameters for their process which could be used to project the cost of using their process to meet tighter sulfur caps.[23] Specifically, Linde provided design parameters for a revamp of an existing highway desulfurization unit to meet a 15 ppm cap standard. The revamp would put an IsoTherming unit upstream of the existing highway diesel fuel hydrotreater.

Linde provided IsoTherming designs for three revamp situations. In the first design, the feedstock consisted of 60 percent straight run and 40 percent LCO. The unhydrotreated sulfur level was just under 2000 ppm and both the existing hydrotreater and the IsoTherming unit operated at 600 psi. In the second design, the feedstock consisted of 60 percent straight run, 30 percent LCO and 10 percent light coker gas oil with an unhydrotreated sulfur level of 9950 ppm. The existing hydrotreater and the IsoTherming unit operated at 950 psi. In the third design, the feedstock was the same as in the second, but the IsoTherming unit was designed to operate at 1500 psi, while the conventional hydrotreating unit operated at 950 psi.

We based our cost projections for the IsoTherming process on the second design. The unhydrotreated sulfur level of more than 9000 ppm is more typical for most refiners than 2000 ppm. The 950 psi design pressure for the IsoTherming unit was also thought to preferable to most refiners than 1500 psi. The higher pressure unit would reduce capital and catalyst costs, but higher hydrogen consumption would offset much of the cost savings. The higher pressure reactors and compressors would also have a longer delivery time and there would likely be fewer fabricators to select from. Thus, given that the savings associated with the higher pressure unit were small, we decided to focus on the 950 psi design.

The information provided by Linde for the 950 psi IsoTherming desulfurization unit is summarized in the following table. The operation and product quality of the IsoTherming unit is shown separate from those for the existing conventional hydrotreater. Again, prior to the revamp, the conventional hydrotreater would have processed this feedstock down to roughly 300-400 ppm sulfur.

Table 7.2-16
Linde IsoTherming Revamp Design Parameters to Produce 10 ppm Sulfur Diesel Fuel

	Feed Quality	IsoTherming Unit and its Product Quality	Conventional Hydrotreater and Final Product Quality
LCO vol %	30		
Straight Run vol %	60		
Light Coker Gas Oil vol%	10		
Sulfur ppm	9950	850	10
Nitrogen	340	38	2
API gravity (degrees)	33.98	34.42	35.84
Cetane Index	44.5	48.5	50.8
H_2 Consumption (scf/bbl)		320	100
Relative H_2 Consumption		75	25
LHSV (hr^{-1})		15/15	3
Relative Catalyst Volume		45	100
Reactor Delta T		15	15
H_2 Partial Pressure		950	950
Electricity (kW)		1525	
Natural Gas (mmbtu/hr)		0	
Steam (lb/hr)		0	

7.2.1.2.3.1 Hydrotreating High Sulfur Distillate Fuel to 15 ppm

The design parameters provided by Linde involve the revamp of an existing conventional hydrotreater currently producing highway diesel fuel (i.e., less than 500 ppm sulfur) to produce diesel fuel with a sulfur level well below 15 ppm. Before addressing this situation, however, we will use the Linde revamp design to project the costs of an IsoTherming unit which processes unhydrotreated distillate fuel (e.g., 3400-10,000 ppm sulfur) down to 7-8 ppm sulfur. This type of unit was not projected to be used under the proposed two-step fuel program. However, it is projected to be used under the one-step alternative fuel program, for which costs are also estimated later in this chapter.

Also, as was done for conventional hydrotreating and the Phillips SZorb process, we will develop cost estimates for applying the IsoTherming process to three individual blendstocks, straight run, LCO and light coker gas oil, in order to be able to project desulfurization costs for individual refineries whose diesel fuel compositions vary dramatically.

We have broken down the derivation of the cost of a stand-alone IsoTherming unit capable of producing 15 ppm diesel fuel into four parts: hydrogen consumption, utilities and yield losses, catalyst cost and capital cost.

Hydrogen Consumption: In this section, we estimate the hydrogen consumption to process individual refinery streams from their uncontrolled levels down to 7-8 ppm sulfur. Linde provided hydrogen consumption estimates for desulfurizing a mixed feedstock of 60 percent straight run, 30 percent LCO and 10 percent coker distillate, but not for specific refinery streams. Additionally, Linde provided information for a hybrid desulfurization unit which is comprised of a Linde IsoTherming unit which is revamping a conventional highway hydrotreater. Upon our request for additional information, Linde informed us that the highway hydrotreater in the above described revamp is operating similar to an IsoTherming unit. Thus, we used the hydrogen consumption estimates in Tables 7.2-16 as if they represented a stand-alone IsoTherming unit.

As a first step in estimating the IsoTherming hydrogen consumption for individual blendstocks, we compared the hydrogen consumption of the Linde IsoTherming process with that of conventional hydrotreating. Table 7.2-16 shows a total hydrogen consumption of consumes 420 scf/bbl to desulfurize untreated diesel fuel to 10 ppm. Using the projected hydrogen consumption for conventional hydrotreating shown in Table 7.2-7 above, the total hydrogen consumption to desulfurize this same feedstock to 7-8 ppm would be 559 scf/bbl. Based on this example, the IsoTherming process appears to only consume 75 percent of that associated with conventional hydrotreating. Thus, we assumed that the Linde IsoTherming process would only use 71% of the hydrogen which we projected above for processing individual blendstocks using conventional hydrotreating. The resulting hydrogen consumptions were 826 scf/bbl for LCO, 638 scf/bbl for other cracked stocks, and 180 scf/bbl for straight run.

As we did for conventional hydrotreating and the Phillips SZorb process, we developed adjustments to these hydrogen consumptions to reflect differing unhydrotreated sulfur levels. We assumed that the hydrogen consumption for IsoTherming process varied in the same proportions as those for conventional hydrotreating because the treated feed sulfur levels were about the same. Thus, the same hydrogen adjustment factors were used (see subsection 7.2.1.2.1.3). The adjustment is applied as a multiplicative factor to the above base hydrogen consumption for each untreated blendstock type. For a refinery with a distillate hydrotreater, it ranged from 0.79 for PADD 5, which has an estimated untreated distillate sulfur level of 2610 ppm, to 1.08 for PADD 3 which has an estimated untreated distillate sulfur level of 11,320 ppm. No adjustment factors are applied to blendstocks which are already hydrotreated. These blendstocks are assumed to contain 340 ppm sulfur. The hydrogen consumption for the IsoTherming process when applied to diesel fuel with this initial sulfur level is described in the next Section 7.2.1.2.3.2 below.

Refineries without a distillate hydrotreater do not have any any hydrotreated blendstocks to blend into their high sulfur distillate. Thus, we estimate lower unhydrotreated sulfur levels for these refineries. The adjustment factors for these refineries ranged from 0.79 for PADD 5, which has an estimated untreated sulfur level of 2540 ppm, to 0.87 for PADD 3 which has a starting sulfur level of 5200 ppm.

Utilities and Yield Losses: We next established the IsoTherming utility inputs for individual blendstocks. The Linde IsoTherming process saves a substantial amount of heat input by conserving the heat of reaction which occurs in the IsoTherming reactors. This conserved energy is used to heat the feedstock to the unit. This differs from conventional hydrotreating which normally must reject much of this energy to avoid coking the catalyst. According to Linde, this allows the IsoTherming process to operate with essentially no external heat input. In the highway hydrotreater revamp which is the source of the information provided by Linde, the existing heater for the highway hydrotreater could essentially be turned off after the IsoTherming process was added. However, there is still the need for a small heater to heat up the feedstock during unit startup. This affects capital costs. However, when averaged over production between start-ups, this little amount of fuel used during start-up is negligible. Thus, we estimate need for either fuel or steam with the IsoTherming process.

As shown in Table 7.2-16, Linde estimated electricity demand at 1525 kilowatts. The unit was designed to process 20,000 bbl/day, so the unit electricity demand was 1.83 kilowatt-hour per barrel (kw-hr/bbl). Because the electricity demand value was not provided separately for the IsoTherming and the original conventional highway hydrotreater, we assumed that this demand applied to a stand-alone IsoTherming unit, as well. Since most of the electrical demand is due to the compression of hydrogen, and we are using the same hydrogen consumption as shown in Table 7.2-16, it is consistent that the electrical demand would be the same.

We compared this electrical demand to that of conventionally hydrotreater treating the same feedstock. Using the elecricity demands from Table 7.2-7 above, we project that the electrical demand of conventional hydrotreating would be 0.83 kW-hr/bbl. Thus, IsoTherming appears to consume 2.2 times as much electicity, probably due to increased liquid pumping associated with liquid recycle to the reactors. We assumed that this 2.2 factor applied to each individual blendstock. Thus, we estimate electricity demand at 1.3, 2.4, and 2.6 kW-hr/bbl for straight run, light coker gas oil, and LCO, respectively.

Linde did not estimate the specific yield losses for the for the IsoTherming process. Upon our request for further information, Linde indicated that their process causes slightly less than half of the yield loss of conventional hydrotreating. Thus, the yield loss of the Linde unit was projected to be 50 percent that of conventional hydrotreating which is proportional to the relative catalyst volume. The resulting projected yield losses are shown below:

	Straight Run	Light Coker Gas Oil	Light Cycle Oil
Diesel	0.75	1.45	1.65
Naphtha	-0.55	-1.00	-1.15
LPG	-0.03	-0.055	-0.06
Fuel Gas	-0.03	-0.085	-0.10

Catalyst Costs: The catalyst cost for the Linde process was estimated based on the relative catalyst volume compared to conventional hydrotreating. As shown in Table 7.2-16, Linde indicated that the catalyst volume for the new IsoTherming reactors contained only 45% of the volume of the new conventional hydrotreating reactors which Linde projects would have been needed to revamp the existing hydrotreater to produce 10 ppm fuel. We assumed that this same relationship would hold for a stand-alone IsoTherming unit. Thus, we multiplied the catalyst costs for conventionally hydrotreating specific blendstocks (shown in Table 7.2-7) by 45%. The resulting IsoTherming catalyst costs were 0.14, 0.27 and 0.36 $/BPSD for straight run, light coker gas oil and LCO, respectively.

Capital Costs: The last aspect of the IsoTherming process to be determined on a per-blendstock basis is its capital cost. Linde's initial submission of process design parameters did not include an estimate of the capital cost. We developed our own estimate from the process equipment included, compared to those involved in conventional hydrotreating. As indicated in Table 7.2-16, the catalyst volume of the two IsoTherming reactors unit (combined LHSV of 7.5) is roughly 8 times smaller than that of a conventional hydrotreating revamp (LHSV of 0.9 per LHSVs for individul blenedstocks from Table 7.2-6). Also, because the IsoTherming reactors use a much higher flowrate and is a totally liquid process (no need for both gas and liquid in the reactor), it eliminates the need for an expensive distributor. As mentioned above, the feed pre-heater can be much smaller and less durable, since it is only required for startup. Finally, the IsoTherming process does not require an amine scrubber to scrub the H_2S from the recycle hydrogen stream.

Based on these differences, we estimated that the total capital cost of a stand-alone IsoTherming unit would be two-thirds that for a conventional hydrotreater. Thus, the capital costs for a 25,000 bbl per day conventional hydrotreater were reduced by one-third. The resulting IsoTherming capital costs for a 25,000 BPSD unit were $21, $25, and $29 million for treating straight run, light coker gas oil and LCO, respectively. The overall capital cost for the specific feed composition shown in Table 7.2-16 above would be $900 per BPSD for the IsoTherming unit, versus $1400 per BPSD for a conventional hydrotreater. More recently, Linde indicated that the capital cost would be roughly $800 per barrel for a 25,000 bbl per day unit.[24] For this analysis, we retained the two-thirds factor relative to conventional hydrotreating ($900 per BPSD). We are considering reducing this cost by 11% to match that of the most recent Linde estimate for our analyses following the proposed rule.

Summary of Process Design Parameters: Table 7.2-17 summarizes the design parameters used for using the Linde IsoTherming process to desulfurize untreated distillate fuel to 10 ppm.

Table 7.2-17
Process Parameters for a Stand-Alone IsoTherming 25,000 BPSD Unit to Produce 10 ppm Sulfur Fuel from Untreated Distillate Fuel

	Straight Run (SR)	Other Cracked Stocks	Light Cycle Oil (LCO)
Capital Cost ($MM)	21	25	29
Hydrogen Demand (scf/bbl)	187	663	858
Electricity Demand (kwh/bbl)	1.71	3.10	3.41
Fuel Gas Demand (btu/bbl)	0	0	0
Catalyst Cost ($/bpsd)	0.16	0.31	0.46
Yield Loss (wt%): Diesel	0.75	1.45	1.65
Naphtha	-0.55	-1.00	-1.10
LPG	-0.03	-0.055	-0.06
Fuel Gas	-0.03	-0.085	-0.10

7.2.1.2.3.2 Desulfurizing 500 ppm Sulfur Diesel Fuel to Meet a 15 ppm Sulfur Cap

The derivation of process design parameters for a IsoTherming unit revamp of a conventional hydrotreater is much more straightforward than that of a stand-alone IsoTherming unit, as the design parameters provided by Linde in Table 7.2-16 were for a revamp. As above, we have broken down the derivation of the cost of a stand-alone IsoTherming unit capable of producing 15 ppm diesel fuel into four parts: hydrogen consumption, utilities and yield losses, catalyst cost and capital cost.

Hydrogen Consumption: Table 7.2-16 depicts the hydrogen consumption for an IsoTherming revamp, but does not provide the hydrogen consumption for the original highway hydrotreater. In estimating hydrogen consumption for a stand-alone IsoTherming unit above, we estimated that the hydrogen consumption for a conventional hydrotreater processing that feedstock to 10 ppm sulfur would consume 559 scf/bbl. The IsoTherming revamp is projected to consumes only 420 scf/bbl, for a savings of 139 scf/bbl. Using the hydrogen consumptions shown in Table 7.2-6, a conventional hydrotreating revamp is projected to consume 193 scf/bbl of hydrogen over that being consumed in the original highway fuel hydrotreater. Thus, the IsoTherming process appears to reduce this incremental consumption by 71% (139/193 * 100%). Given that we had to project the hydrogen consumption of the original hydrotreater, we decided to only project a 60% savings for an IsoTherming revamp, rather than 71%. We will review this estimate for future analyses as additional data from the IsoTherming revamp being installed at a Giant refinery becomes available. Reducing the hydrogen consumptions shown in Table 7.2-6 by 60%, the resulting hydrogen consumptions for an IsoTherming revamp were 150 scf/bbl for LCO, 92 scf/bbl for other cracked stocks, and 38 scf/bbl for straight run.

Utilities and Yield Losses: We followed the same methodology for estimating electricity demand as we did above for hydrogen consumption. We estimated above that the electricity demand for a conventional hydrotreater processing that feedstock to 10 ppm sulfur would consume 0.83 kW-hr/bbl. The IsoTherming revamp is projected to consume 1.83 kW-hr/bbl, an increase of 1.0 kW-hr/bbl. Using the electricity demand shown in Table 7.2-6, a conventional hydrotreating revamp is projected to use 0.53 kW-hr/bbl of electricity over that being used in the original highway fuel hydrotreater. Thus, the IsoTherming process appears to increase this incremental usage by 190% ((1.53/0.53 - 1) * 100%). Given that we had to project the electricity demand of the original hydrotreater, we decided to project a slight larger increase of 225% for an IsoTherming revamp, rather than 190%. We will review this estimate for future analyses as additional data from the IsoTherming revamp being installed at a Giant refinery becomes available. Increasing the electricity demand shown in Table 7.2-6 by 225%, the resulting electricity demand for an IsoTherming revamp were 2.6 kW-hr/bbl for LCO, 2.3 kW-hr/bbl for other cracked stocks, and 1.3 kW-hr/bbl for straight run.

Regarding fuel gas consumption, the total fuel gas consumption for a stand-alone IsoTherming unit was projected above to be zero, due the enhanced ability to conserve heat generated in the aromatic saturation reactions which accompany desulfurization. The process projections shown in Table 7.2-16 above show no consumption of natural gas by the unit. Thus, it would seem reasonable to project that a Linde revamp would cause no increase in fuel gas consumption. In fact, if the total use of natural gas was zero, one might expect that the IsoTherming revamp actually reduced fuel gas consumption, as the original hydrotreater would have been consuming some fuel gas. However, to be conservative, we projected that a IsoTherming revamp would require the same fuel gas consumption as that of a conventional hydrotreating revamp. We will review this estimate for future analyses as additional data from the IsoTherming revamp being installed at a Giant refinery becomes available.

As mentioned above, Linde did not provide estimates of yield losses for the IsoTherming process. We estimated that a stand-alone IsoTherming unit would reduce yield losses by 45% compared to a stand-alone convention hydrotreater. Table 7.2-6 shows that the yield loss for straight run feed is 1.0% for a conventional hydrotreating revamp and Table 7.2-7 shows a 1.5% loss for a grass roots conventional hydrotreater. Thus, the yield losses for a conventional hydrotreating revamp is two-thirds of the yield loss for a grass roots conventional hydrotreater. Thus, the original highway fuel hydrotreater has a yield loss of 0.5% for straight run, consistent with that shown in Table 7.2-11.

If the IsoTherming revamp reduces the yield loss by 45%, its yield loss for straight run is 55% of 1.5%, or 0.82%. Subtracting out the 0.5% loss of the original highway hydrotreater means that the IsoTherming revamp had an incremental yield loss of 0.32%, or 32% of the 1.0% yield loss projected for the conventional hydrotreating revamp. Thus, we projected that all of the yield losses shown in Table 7.2-6 for a conventional hydrotreating revamp would be only 32% as large for an IsoTherming revamp.

	Straight Run	Light Coker Gas Oil	Light Cycle Oil
Diesel	0.32	0.61	0.70
Naphtha	-0.22	-0.42	-0.48
LPG	-0.01	-0.02	-0.03
Fuel Gas	-0.01	-0.035	-0.04

Catalyst Costs: Consistent with the relative catalyst cost for a stand-alone IsoTherming unit, we project that the catalyst cost for an IsoTherming revamp would be 45% of that for a conventional hydrotreating revamp.

Capital Costs: Consistent with the relative capital cost for a stand-alone IsoTherming unit, we project that the capital cost for an IsoTherming revamp would be 45% of that for a conventional hydrotreating revamp.

Summary of Process Design Parameters: The inputs into our cost model for treating already treated non-highway diesel fuel by the individual refinery streams which is presumed to be 340 ppm is summarized in the following table.

Table 7.2-18
Process Projections for an IsoTherming Revamp of a Conventional Hydrotreater
to Meet a 15 ppm Cap Standard

	Straight Run (SR)	Other Cracked Stocks	Light Cycle Oil (LCO)
Capital Cost ($MM)	10.6	12.5	14.5
Unit Size (bbl/stream Day)	25,000	25,000	25,000
Hydrogen Demand (scf/bbl)	38	92	150
Electricity Demand (kwh/bbl)	1.30	2.28	2.60
Fuel Gas Demand (btu/bbl)	0	0	0
Catalyst Cost ($/bpsd)	0.09	0.17	0.22
Yield Loss (wt%)			
Diesel	0.25	0.48	0.55
Naphtha	-0.18	-0.33	-0.38
LPG	-0.01	-0.02	-0.02
Fuel Gas	-0.01	-0.03	-0.03

7.2.1.2.4 Characterization of Vendor Cost Estimates

Applicability to Specific Refineries: The information provided by the vendors is based on typical diesel fuels or diesel fuel blendstocks. However, in reality, diesel fuel (especially LCO, and to a lesser degree other cracked stocks) varies in desulfurization difficulty based on the amount of sterically hindered compounds present in the fuel, which is determined by the endpoint of diesel fuel, and also by the type of crude oil being refined and other unit processes.

The vendors provided cost information based on diesel fuels with T-90 distillation points which varied from 605 ˚F to 630 ˚F, which would roughly correspond to distillation endpoints of 655 ˚F to 680 ˚F. These endpoints can be interpreted to mean that the diesel fuel would, as explained in Chapter V above, contain sterically hindered compounds. Other diesel fuels or diesel fuel blendstocks, such as the straight run diesel fuel in the SZorb estimates, are lighter and would not contain sterically hindered compounds. However, a summer time diesel fuel survey for 1997 shows that the endpoint of highway diesel fuel varies from 600 ˚F to 700 ˚F, thus the lighter diesel fuels would contain no sterically hindered compounds, and the heavier diesel fuels would contain more.[25] Our analysis attempts to capture the cost for each refinery to produce highway diesel fuel which meets the 15ppm cap sulfur standard, however, we do not have specific information for how the highway diesel endpoints vary from refinery to refinery, or from season to season. Similarly, we do not have information on what type of crude oil is being processed by each refinery as the quality of crude oil being processed by a refinery affects the desulfurization difficulty of the various diesel fuel blendstocks. Diesel fuel processed by a particular refiner can either be easier or more difficult to treat than what we estimate depending on how their diesel fuel endpoint compares to the average endpoint of the industry, and depending on the crude oil used. For a nationwide analysis, it is appropriate to base our cost analysis for each refinery on what we estimate would be typical or average qualities for each diesel fuel blendstock. Some estimates of individual refinery costs will be high, others will be low, but be representative on average.

Accuracy of Vendor Estimates: We have heard from refiners in the past that the vendor costs are optimistic and need to be adjusted higher to better assess the costs. While the vendors costs may be optimistic, we believe that there are a multitude of reasons why the cost estimates should be optimistic.

First, in specific situations, capital costs can be lower than what the vendors project for a generic refinery. Many refiners own used reactors, compressors, and other vessels which can be employed in a new or revamped diesel hydrotreating unit. We do not know to what extent that additional hydrotreating capacity can be met by employing used vessels, however, we believe that at least a portion of the capital costs can be offset by used equipment.

There are also operational changes which refiners can make to reduce the difficulty and the cost of desulfurizing highway diesel fuel. Based on the information which we received from vendors and as made apparent in our cost analysis which follows, refiners with LCO in their diesel fuel would need to hydrotreat their highway diesel pool more severely resulting in a higher cost to meet the cap standard. We believe that these refiners could potentially avoid some or much of this higher cost by pursuing two specific options. The first option which we believe these refiners would consider would be to shift LCO to heating oil which does not face such stringent sulfur control . The more lenient sulfur limits which regulate heating oil provide room for blending in substantial amounts of LCO. The refineries which could take advantage of shifting LCO to the heating oil pool are those in the Northeast and on the Gulf Coast which have access to the large heating oil market in the Northeast. Another option is for refiners to shift some of their LCO to the locomotive and marine markets. While these markets would be regulated to a 500 ppm sulfur standard, it is less stringent and does not require the aggressive desulfurization of the sterically hindered compounds. Because of the low cetane value inherent with LCO, refiners cannot simply dump a large amount into locomotive and marine diesel since those two pools must meet an ASTM cetane specification. Thus, we believe that refiners could distill its LCO into a light and heavy fraction and only shift the heavy fraction to off-highway, locomotive, and marine diesel fuels. Essentially all of the sterically hindered compounds distill above 630 °F, so if refiners undercut their LCO to omit these compounds, they would cut out about 30 percent of their LCO. We expect that refiners could shift the same volume of non-LCO distillate from these other distillate pools to the non-highway pool to maintain current production volumes of all fuels. In addition to the cetane limit which restricts blending of LCO into non-highway diesel, the T-90 maximum established by ASTM limits would limit the amount of LCO, and especially heavy LCO, which can be moved from nonroad diesel fuel into these other distillate streams. The exception, of course, would be to move this dirty distillate fraction into number 4 or number 6 marine bunker fuel. For those refineries which could trade the heavy portion of LCO with other blendstocks in the high sulfur pool from own refinery or other refineries, we presume that those refiners could make the separations cheaply by using a splitting column for separating the undercut LCO from the uncracked heavy gasoil in the FCC bottoms.

Another option for refineries which are faced with treating LCO in its nonroad diesel fuel would be to sell off or trade their heavy LCO to refineries with a distillate hydrocracker. This is a viable option only for those refineries which are located close to another refinery with a distillate hydrocracker. The refinery with the distillate hydrocracker would upgrade the purchased LCO into gasoline or high quality diesel fuel. To allow this option, there must be a way to transfer the heavy LCO from the refinery with the unwanted LCO to the refinery with the hydrocracker, such as a pipeline or some form of water transport. We asked a refinery consultant to review this option. The refinery consultant corroborated the idea, but commented that the trading of blendstocks between refineries is a complicated business matter which is not practiced much outside the Gulf Coast, and that the refineries with hydrocrackers that would buy up and process this low quality LCO may have to modify their distillate hydrocrackers.[26] The modification which may be needed would be due to the more exothermic reaction temperature of treating LCO which could require refiners to install additional quenching in those hydrocrackers. Additionally, LCO can demand 60 to 80 percent more hydrogen for processing than straight run material. The refineries which could potentially take advantage of selling or trading their LCO to these other refineries are mostly located in the Gulf Coast where a significant number of refineries have hydrocrackers and such trading of blendstocks is common. However, there are other refineries outside the Gulf Coast which could take advantage of their very close location to another refinery with a distillate hydrocracker. Examples for these refining areas where a hydrocracker could be shared include the Billings, Montana area and Ferndale, Washington.

As we summarized in Chapter 5, catalysts are improving and expected to continue to improve. Our costs are based on vendor submissions and incorporate the most advanced catalysts available. As catalysts continue to improve, the cost of desulfurizing diesel fuel will continue to decrease.

In summary, if the vendor cost estimates are optimistically low, there are a number of reasons why the cost of desulfurizing highway diesel fuel to meet the 15 ppm cap standard are likely to be low. Vendors are expected to continue to improve their desulfurization technology such as the activity of their catalysts. Also, refiners have several cost cutting options at their disposal such as using existing spare equipment to lower their capital costs. Also, refiners may be able to resort to either of two operational options to reduce the amount of LCO in their highway diesel fuel.

We are aware that there are potentially other capital and operating costs in the refinery which would contribute the projected cost of desulfurizing diesel fuel beyond that provided to us by the vendors. For example, refiners may need to expand their amine plant or their sulfur plant to enable the processing of the sulfur compounds removed from diesel fuel. Then the small amount of additional sulfur compounds treated would incur additional operating costs. Thus, as described below, we adjusted the projected capital and operating costs upward to account for these other potential costs which we have not accounted for explicitly.

7.2.1.3 Composition of Distillate Fuel by Refinery

In the previous section, we established distinct desulfurization costs for the various blendstocks comprising diesel fuel. To apply these costs to each refinery, we must estimate the each refinery’s diesel fuel composition. Refiners do not publish this information, so we estimated these compositions from other publically available sources of information. The fraction of LCO in distillate fuel is addressed first, then we estimate the fraction of other cracked stocks and lastly, the fraction of hydrocrackated stocks. By estimating the fractions of each refinery’s number two distillate comprised by these various blendstocks, the remaining fraction is comprised of straight run distillate. In addition to these primary sources of distillate blendstocks, the fraction of distillate currently being hydrotreated also affects the cost of further sulfur control, particularly the required consumption of hydrogen. Thus, the fraction of distillate fuel which is currently hydrotreated is also estimated below for each refinery. Finally, how distillate composition might be changing over time is discussed.

Light-Cycle Oil: First, we estimated the volume of LCO produced by each refinery based on the capacity of its Fluidized Cat Cracker unit (FCC unit). The Oil and Gas Journal (OGJ) publishes information on the capacity of major processing units for each refinery in the country, including the FCC unit.[27] Based on the results of API/NPRA’s Refining Operations and Product Quality survey, the FCC units typically operate at 90 percent of capacity.[28] The API/NPRA survey also shows that number two distillate produced nationally (outside of California) contains 21 percent LCO averaged over the entire pool. However before using this information for estimating the amount of FCC feed which is produced as LCO for each refinery, we needed to take two important steps to facilitate the calculation. First, it was necessary to account for the LCO which is processed by the hydrocracker in the refinery. As discussed above, refineries with hydrocrackers normally send their LCO to the hydrocracker and convert most of it to gasoline. Thus, for refineries with distillate hydrocrackers, we reduced their estimated LCO production by the operational capacity of their hydrocracker (again estimated to be 90% of rated capacity per the above API/NPRA survey). Also, an FCC feed hydrotreater can significantly improve the quality of LCO. However, we do not believe that refineries outside of California[e] have FCC feed hydrotreaters with sufficiently high hydrogen pressure to produce this quality improvement. Also, we do not have a source of desulfurization costs for LCO produced from an FCC unit with feed pretreatment versus more typical LCO. Thus, all LCO was assumed to have the same quality.

Second, EIA regularly collects data from refiners, including their production volumes of high and low sulfur distillate fuel. According to EIA, 138 U.S. refiners produced a total of 55 billion gallons of distillate in 2000, with 17 billion gallons (about 31 percent) being high sulfur diesel fuel produced by 105 refineries. The 1996 API/NPRA survey shows that the LCO fraction of low sulfur and high sulfur distillate fuel are quite similar. Therefore, for the purpose of estimating the fraction of each refinery's feed to the FCC unit which is produced as LCO, of we assumed that the LCO fraction of each refinery's low and high sulfur distillate fuel were equal.

We then backcalculated from the aggregate figure that 21 percent of the nation's refineries' number 2 distillate is LCO, and based on the premise that refineries with hydrocrackers processed their LCO in that unit, that refineries with FCC units produce 25 percent LCO from the feed to those units. We then categorized the 105 refineries producing high sulfur distillate based on the LCO fraction of their distillate pool at 5 or 10 percent intervals from 0 to 60 percent. The distribution of refineries by fraction of LCO is summarized in Table 7.2-19.

[E] This analysis does not model the Federal nonroad standards applying in California since it is expected that California will be implementing its own program before the Federal program takes effect.

Table 7.2-19
Distribution of LCO in Distillate Fuel by Refinery
(High Sulfur Producing U.S. Refineries)

	Percentage of LCO in the Distillate Pool							
	0%	<10%	<20%	<25%	<30%	<40%	<50%	<80%
Number of Refineries	44	45	51	61	81	96	101	104
Cumulative Percentage of US Nonroad Diesel Volume	26	27	34	52	74	87	97	99

As the table shows, we estimate that distillate fuel produced by refineries which produce high sulfur distillate contains anywhere from zero LCO to over 80 percent LCO. The table also shows that 44 U.S. refineries, which produce about 26 percent of the high sulfur distillate in the U.S., blend no LCO into their distillate. The above table also reveals that the distillate from the remaining 61 refineries averages about 28 percent LCO by volume.

Other Cracked Stocks: In addition to LCO, nonroad diesel fuel is comprised of other cracked stocks such as light coker gas oil, light visbreaker gas oil, and light thermally cracked gas oil. These other cracked stocks are somewhat more difficult to treat than straight run distillate, but less difficult to treat than LCO. Light coker gas oil dominates this intermediate group of blendstocks and we have estimates available for its desulfurization costs. Therefore, we estimated the fraction of all of these other cracked stocks in each refinery's high sulfur distillate fuel and treat the volume as light coker gas oil for cost estimation purposes.

Similar to our approach for LCO, we based the volume of each of these cracked stocks on the capacity of the refining units which produce them, namely delayed and fluid cokers, visbreakers, and thermal crackers. Based on the above mentioned API/NPRA survey, we estimate that all of these units operate at 90 percent of capacity. Based on confidential estimates from a refining industry consultant, we estimate that 30 percent of delayed coker and 15 percent of the other units' production is distillate blended into the distillate pool. As we did with our procedure for LCO, refineries with hydrocrackers were assumed to send these other cracked stocks to the hydrocracker for conversion to gasoline to the extent that capacity remained after any LCO was processed by that unit. We also again spread the volume of these other cracked stocks proportionately across each refinery's production of low and high sulfur distillate fuel based on the information in the API/NPRA survey [29] which shows that the other cracked stocks is fairly well equally distributed across these two pools.

Summing the volume of other cracked stocks in high distillate across all refineries, we found that about 8 percent of the entire distillate fuel volume produced by high sulfur distillate producing refineries is comprised of these other cracked stocks. This value agrees well with the 1996 API/NPRA survey of distillate fuel. The fractions which cracked stocks comprise of the total distillate pool for refineries which produce high sulfur distillate fuel was characterized for the industry as a whole and summarized below in Table 7.2-20.

Table 7.2-20
Distribution of Other Cracked Stocks in Distillate Fuel by Refinery
(High Sulfur Producing U.S. Refineries)

	Percentage of Other Cracked Stocks in the Distillate Pool						
	0%	<10%	<15%	<20%	<25%	<30%	<40%
Number of Refineries	74	76	86	94	97	102	105
Cumulative Percentage of US non-Highway Diesel Volume	48	51	64	76	78	96	100

As shown, we estimate that almost half of distillate fuel in the U.S, which is produced by 74 refineries, does not contain other cracked stocks from cokers, visbreakers and thermal crackers. Of the refineries which are projected to blend other cracked stocks into their distillate pool, the analysis predicts that, on average, the distillate fuel from these refineries contains approximately 19 percent of other cracked stocks.

Hydrocracked: In the U.S., hydrocrackers are almost exclusively used to crack undesirable distillate blendstocks, primarily LCO, into more desirable products, such as gasoline. However, not all of this distillate material is converted to gasoline. The portion which remains distillate is of high quality.[f] We again obtained the hydrocracker capacity by refinery from the OGJ. The 1996 API/NPRA survey of distillate fuel composition indicated that 5.8 percent of all distillate was hydrocracked. Dividing 5.8% of total distillate production in 2000 by total hydrocracker capacity, we found that about 20 percent of the hydrocracker capacity is hydrocracked distillate, which is also termed hydrocrackate. This percentage was assumed to apply to all hydrocrackers.

Unlike the other blendstocks, the 1996 API/NPRA survey indicated that hydrocrackate comprises a smaller percentage of low sulfur diesel fuel (4.4%) than high sulfur distillate fuel (8.8%). Thus, for refineries which produced both low and high sulfur distillate fuel in 2000, we allocated a higher percentage of hydrocrackate to their high sulfur pool than their low sulfur pool until the overall percentage of hydrocrackate in low and high sulfur distillate fuel pools equaled 4.4 percent and 8.8 percent, respectively.

Hydrotreated Material in High Sulfur Distillate: The 1996 API/NPRA fuel quality survey shows that a significant percentage of the blendstocks comprising high sulfur distillate are

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[F] According to Mathpro, hydrocracked distillate is high in cetane (~46) and low in sulfur (~100 ppm) relative to the feedstock which if it is LCO is low in cetane (~25) and high in sulfur (~12,000 ppm) hydrotreated, despite the fact that the final sulfur level is 2000 ppm or more. This is likely necessary to improve the stability of untreated LCO, as well as meet applicable cetane and sulfur specifications with blendstocks which can exceed 10,000 ppm sulfur and have a cetane number of less than 15 prior to hydrotreating. The fact that a portion of high sulfur distillate fuel is currently hydrotreated is important, because this removes all of the olefins and saturates some of the aromatics, reducing subsequent hydrotreating costs. While hydrotreating also removes some of the sulfur from these streams, our estimates of the amounts of sulfur in high sulfur distillate come from measurements of finished high sulfur distillate. Thus, while hydrotreated blendstocks have reduced sulfur levels, this means that the unhydrotreated blendstocks have higher sulfur levels, which combined, produce the final, surveyed sulfur level. The API/NPRA survey shows that the fraction of the high sulfur distillate pool which is desulfurized varies significantly between PADDs. Thus, the refinery model was calibrated against the 1996 API/NPRA Refinery Survey at the PADD level instead of at the national level. Table 7.2-21 summarizes the fraction of high sulfur distillate which is hydrotreated in each PADD.

Table 7.2-21
Hydrotreated Percentage of High Sulfur Distillate Blendstocks

PADD	Percent Hydrotreated
1	27
2	31
3	44
4	17
5 (CA excluded)	2
AK	0

As Table 7.2-3 shows, PADD 3 has the highest percentage of its high sulfur distillate pool hydrotreated at 44 percent. None of Alaska's fuel is believed to be hydrotreated since none of the refineries located in Alaska have distillate hydrotreaters.

The hydrotreated blendstocks of the high sulfur distillate pool are assumed to be treated to meet the current highway sulfur standard average of 340 ppm. We believe that this is reasonable because many refiners who are blending their nonroad diesel fuel using both hydrotreated and unhydrotreated streams likely only have a single hydrotreater and they are simply blending some of their highway diesel fuel with high sulfur distillate to produce a product which meets either nonroad or heating oil standards. There could be refiners who have dedicated hydrotreaters in their refineries for treating high sulfur distillate for producing nonroad or heating oil directly, or for blending with other high sulfur distillate for producing nonroad or heating oil. Thus the hydrotreated product could be higher or lower than the current average of 340 ppm. However, as seen below, this would simply result in a lower or higher starting sulfur level for the balance of the pool which is not desulfurized and the net desulfurization cost would be about the same. Also, one cannot tell by looking at the U.S. refinery unit capacities in the Oil and Gas Journal if there is dedicated nonroad distillate hydrotreating capacity or not. Assigning the hydrotreated stocks a sulfur level of 340 ppm simplifies the analysis.

As seen in Section 7.1, average sulfur levels were calculated for each PADD. Using these as a starting point, PADD-specific starting sulfur levels were estimated for each PADD depending on whether the refinery had a distillate hydrotreater or not. If a refinery did not have a distillate hydrotreater, then its starting sulfur level is the same as that reported in Section 7.1. However, if the refinery did have a diesel hydrotreater, then the sulfur level for the unhydrotreated portion of the nonroad pool was calculated. One adjustment was made to the average starting sulfur levels of PADDs 1 and 3. Because the high sulfur producing refineries in those two PADDs have hydrocrackers, the sulfur levels were adjusted to estimate the sulfur level of the nonhydrocracked blendstocks. Excluding hydrocracked distillate from the average sulfur level is important as hydrocracked distillate is not expected to be treated in new distillate hydrotreater equipment added to comply with the 500 ppm and 15 ppm sulfur cap standards. The various sulfur levels are summarized in Table 7.2-22 and these are used to estimate the cost of desulfurizing nonroad diesel fuel.

Table 7.2-22
High Sulfur Distillate Fuel Sulfur Levels[a]
(Excludes Hydrocracked Blendstocks)

PADD	Sulfur Level of High Sulfur Distillate in Refineries without Hydrotreaters	Sulfur Level of Hydroteated Blendstocks in Refineries with Distillate Hydrotreaters	Sulfur Level of non-Hydrotreated High Sulfur Distillate in Refineries with Distillate Hydrotreaters
1	3420	340	6130
2	3000	340	5400
3	5200	340	11,320
4	2700	340	4200
5 (Excluding CA)	2540	340	2600
Alaska	2540	—	2540

[a] The values in the third column are calculated from the sulfur levels of the first column, the sulfur levels of the second column and the percentages in Table 7.3-3

Trends in Distillate Fuel Composition: It is likely that refiners will want to shift their blendstocks in an effort to reduce their costs for complying with the 15 ppm highway diesel fuel standard in 2006. Directionally, refiners would likely shift their more difficult to treat blendstocks (LCO and other cracked stocks) to high sulfur distillate and their easier to treat blendstocks (straight run and hydrocrackate) to highway fuel. Heating oil must meet at least the 5000 ppm sulfur specification, as well as more stringent state specifications, as low as 2000 ppm. Most high sulfur diesel fuel and heating oil is shipped as a single fuel, so high sulfur diesel fuel often must meet state sulfur standards for heating oil and heating oil must have a cetane number of at least 40. However, nonroad diesel fuel must continue to meet a 40 cetane specification and a 500 ppm sulfur specification. Since straight run and hydrocrackate generally have higher cetane levels and lower sulfur levels than the other blendstocks, only a limited amount of such shifting is feasible.

The sulfur content and cetane number of each type of blendstock can vary widely depending on the specific crude oil processed and the design of the refining equipment employed. Therefore, estimating the degree to which each refinery could shift its blendstocks around to minimize its desulfurization costs under the highway diesel fuel rule was not possible. However, in an attempt to partially reflect shifting that could occur, we shifted some hydrocrackate from selected refineries' high sulfur distillate pool to their low sulfur pool. This was only done when a blendstock with relatively high cetane and low sulfur was available to replace the hydrocrackate. The only blendstock considered to be of sufficiently high quality to replace hydrocrackate was distillate which had been processed through a distillate hydrotreater. Once hydrotreated, typically blended distillate tends to have reasonable cetane and sulfur levels, so the specific composition of the hydrotreated distillate is not critical. Thus, only those refineries with both hydrocrackers and distillate hydrotreaters were assumed to move the hydrocracked distillate over to the highway pool. The composition of the hydrotreated distillate shifted to the high sulfur distillate fuel pool was assumed to match the composition of all the non-hydrocracked distillate material produced by the refinery. Since the majority of current low sulfur diesel fuel is hydrotreated to meet the 500 ppm cap, plenty of hydrotreated material was usually available for swapping for the hydrocracked distillate available from the high sulfur distillate pool. Thus, most of the hydrocrackate from refineries producing both low and high sulfur distillate in 2000 was shifted to the low sulfur fuel pool. After this shift, hydrocracked distillate comprised 2.6 percent of the high sulfur distillate pool and 7.2 percent of the highway diesel pool.

The distillate fuel compositions estimated above are based primarily on data from the 1996 API/NPRA survey and current refinery unit capacities. We assumed that these compositions would remain constant throughout the timeframe of the analysis: 2007-2030. A recent presentation by EIA indicates that this is not likely to be the case. While the volumes of light and medium crude oils processed by U.S. refineries has been relatively constant over the past 15 years, the volume of heavy crude oils has increased significantly. This has lead to an increase in the fraction of crude oil volume processed through conversion units, particularly cokers and hydrocrackers. FCC unit capacity also increased slightly as a fraction of total crude oil distillation capacity Thus, the 1996 API/NPRA distillate fuel quality survey likely underestimates the amount of other cracked stocks and hydrocracked material in distillate fuel. While this analysis does not reflect this trend, we plan to incorporate this trend into future estimates of the cost of desulfurizing diesel fuel.

7.2.1.4 Summary of Cost Estimation Factors

This section presents a number of costs, such as those for electricity and natural gas, as well as cost adjustment factors which are applicable to all three of the above desulfurization technologies.

7.2.1.4.1 Capital Cost Adjustment Factors

Unit Capacity: The capital costs supplied by the vendors of desulfurization technologies apply to a particular volumetric capacity. We adjust these costs to represent units with lower or higher volumetric capacity using the "sixth tenths rule."[g] According to this rule, commonly used in the refining industry, the capital cost of a piece of equipment varies in proportion to the ratio of the new capacity to the base capacity taken to some power, typically 0.6. This allows us to estimate how the capital cost might vary between refineries due to often large differences in the amount of distillate fuel which they are desulfurizing.

Stream Day Basis: The EIA data for the production of distillate by various refineries is on a calendar basis. In other words, it is simply the annual distillate production volume of the period of interest divided by the number of days in the period. However, refining units are designed on a stream day basis. A stream day is a calendar day during which the unit is actually or expected to be operational. Refining units must be able to process more than the average daily throughput due to changes in day-to-day operations, to be able to handle seasonal difference in diesel fuel production and to be able to re-treat off-specification batches. The capital costs for the three desulfurization technologies were provided on a stream day basis.

Actual refining units often operate 90 percent of the time, or in other words, can process 90% of their design capacity over the period of a year. However, when designing a new unit, it is typical to assume a lower operational percentage. We have assumed that a desulfurization unit would be designed to meet its annual production target while operating only 80% of the time. This means that the unit capacity in terms of stream days must be 20 percent greater than the required calendar day production.

Off-site and Construction Location Costs: The capital costs provided by vendors do not include off-site costs, such as piping, tankage, wastewater treatment, etc. They also generally assume construction on the Gulf Coast, which are the lowest in the nation. Off-site costs are typically assumed to be a set percentage of the on-site costs.

The off-site cost factors and construction location cost factors used in this analysis were taken from Gary and Handewerk.[30] The offsite factors provided by Gary and Handewerk apply to a new desulfurization unit. Off-site costs are much lower for a revamped unit, as the existing unit is already connected to the other units of the refinery, utilities, etc.. Thus, we reduced the off-site factors for revamped units by 50%.[31]

[G] The capital cost is estimated at this other throughput using an exponential equation termed the "six-tenths rule." The equation is as follows: $(Sb/Sa)^e xCa=Cb$, where Sa is the size of unit quoted by the vendor, Sb is the size of the unit for which the cost is desired, e is the exponent, Ca is the cost of the unit quoted by the vendor, and Cb is the desired cost for the different sized unit. The exponential value "e" used in this equation is 0.9 for splitters and 0.65 for desulfurization units (Peters and Timmerhaus, 1991).

The off-site factors vary by refinery capacity, while the construction location factors vary between regions of the country.[32] In our analysis of the costs for the Tier 2 gasoline sulfur rule, we estimated the average of each factor for each PADD. There, all the naphtha desulfurization units were new units. Thus, the PADD-average off-site factors developed for that rule were simply divided by two to estimate PADD-average factors for revamped units here. The resulting factors are summarized in Table 7.2-23.

Table 7.2-23
Offsite and Construction Location Factors

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Offsite Factor					
- New Unit	1.26	1.26	1.20	1.30	1.30
- Revamped Unit	1.13	1.13	1.10	1.15	1.15
Construction Location Factor	1.5	1.3	1	1.4	1.2

Additional Capital Costs: There are also likely some capital costs associated with equipment not included in either the vendor's estimates, nor the general off-sites. Examples would be expansions of the amine and sulfur plants to address the additional sulfur removed, a new sulfur analyzer. To account for these other capital costs, and for other contingencies, capital costs (including off-sites) were increased by 15 percent, typical for this type of analysis.[33] In addition, we increased this factor to 18% to include the costs of starting up a new unit.[34]

Capital Amortization: The economic assumptions used to amortize capital costs over production volume and the resultant capital amortization factors are summarized below in Table 7.2-24.[35] These inputs to the capital amortization equation are used in the following section on the cost of desulfurizing diesel fuel to convert the capital cost to an equivalent per-gallon cost.[h]

Table 7.2-24
Economic Cost Factors Used in Calculating the Capital Amortization Factor

Amortization Scheme	Depreciation Life	Economic and Project Life	Federal and State Tax Rate	Return on Investment (ROI)	Resulting Capital Amortization Factor
Societal Cost	10 Years	15 Years	0 %	7%	0.11
Capital Payback	10 Years	15 Years	39 %	6% 10%	0.12 0.16

[H] The capital amortization factor is applied to a one time capital cost to create an amortized annual capital cost which occurs each and every year for the 15 years of the economic and project life of the unit. This implicitly assumes that refiners would reinvest in desulfurization capacity after 15 years at the same capital cost and amortized annual cost, and amortized cost per gallon.

The capital amortization scheme labeled Societal Cost is used most often in our estimates of cost made below. It excludes the consideration of taxes, since taxes are considered to be transfer payments between various sectors of the economy and not true economic costs. The other two cost amortization schemes include corporate taxes, to represent the cost as the regulated industry might view it. The lower, 6%, rate of return represents the rate of return for the refining industry over the past 10-15 years. The higher, 10%, rate of return represents the rate of return which would be expected for an industry having the general aspects of the refining industry.

7.2.1.4.2 Fixed Operating Costs

Operating costs which are based on the cost of capital are called fixed operating costs. These costs are termed fixed, because they are normally incurred whether or not the unit is operating or shutdown. Fixed operating costs normally include maintenance needed to keep the unit operating, building costs for the control room and any support staff, supplies stored such as catalyst, property taxes and insurance.

We included fixed operating costs equal to 6.7% of the otherwise fully adjusted capital cost (i.e., including offsite costs and adjusting for location factor and including the capital cost contingency) and this factor was adjusted upwards using the operating cost contingency factor.[36] The breakdown of the base fixed operating cost percentage is as follows:
Maintenance costs: 3%
Buildings: 1.5%
Land: 0.2%
Supplies: 1%
Insurance: 1%.

Annual labor costs were taken from the refinery model developed by the Oak Ridge National Laboratory (ORNL).[37] This model has often been used by the Department of Energy to estimate transportation fuel quality and the impact of changes in fuel quality on refining costs. Labor costs are very small, on the order of one thousandth of a cent per gallon.

7.2.1.4.3 Utility and Fuel Costs

Variable operating costs only accrue as the unit is operating. Thus, they are usually based on unit throughput. When the unit is not operating, variable operating costs are zero. Thus, variable operating costs are based on calendar day throughput, not stream day capacity, to avoid over-counting these costs.

We obtained utility costs from EIA’s 1999 Petroleum Marketing Annual report, which provides these costs by PADD.[38] We considered updating these costs. However, a review of more recent electricity showed little change from 1999. The price of liquid fuels changed significantly from 1999, but did not appear to represent long term trends. Thus, 1999 liquid fuel prices were also retained, with one change. We did add 5 c/gal to the price of high sulfur distillate fuel to represent the added cost of meeting the 15 ppm sulfur cap to.

Natural gas prices have been particularly volatile over the past three years, as natural gas use in electricity generation is increasing rapidly. Therefore, the price over any short period of time is unlikely to represent long term prices well. Thus, natural gas prices were averaged over 5 years starting at the end of 1996 and this average price was used here.

Steam demand is presented above in terms of pounds per hour. This was converted to BTUs per hour, assuming that the steam was provided at 300 psi (809 BTU per pound). We assume that the steam is generated using natural gas as fuel, at an efficiency of 50%, which was taken from Perry's Handbook.[39]

These utility and fuel costs are summarized in Table 7.2-25. For future analyses, we are considering using projections of future utility and fuel prices from EIA's most recent Annual Energy Outlook.

Table 7.2-25
Summary of Costs From EIA Information Tables for1999, and Other Cost Factors

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Electricity (cents per kilowatt-hour)	8.35	6.40	6.66	5.4	7.18
LPG (dollars per barrel)	17.09	14.11	14.49	14.53	17.05
Highway Diesel (cents per gallon)	53.1	55.9	51.5	62.4	64.0
Nonhighway Diesel (cents per gallon)	49.3	55.7	48.6	60.4	58.9
Gasoline (dollars per barrel)	27.0	25.9	24.9	28.9	30.0
Natural Gas ($/MMbtu)	4.15	4.24	2.98	3.15	3.91

7.2.1.4.4 Hydrogen Costs

Hydrogen costs are estimated for each PADD based on the capital and operating costs of installing or revamping a hydrogen plant fueled with natural gas. The primary basis for these costs is a technical paper published by Air Products, which is a large provider of hydrogen to refineries and petrochemical plants.[40] The particular design evaluated was a 50 million scf/day steam methane reforming hydrogen plant installed on the Gulf Coast. The capital cost includes a 20% factor for offsites. The process design parameters from this paper are summarized in the Table 7.2-26.

Table 7.2-26
Process Design Parameters for Hydrogen Production

Cost Component	Dollars per thousand standard cubic feet ($/MSCF)
Natural Gas	1.18
Utilities	
Electricity	0.03
Water	0.03
Steam	-0.07
Capital/Fixed Operating Charges	0.83
Total Product Cost	2.00

Notes: Natural Gas @ $2.75/MMBTU; Steam @ $4.00/M lbs; Electricity @ $0.045 KWH

The estimates shown in Table 7.2-26 were adjusted to reflect natural gas and utility costs in each PADD (shown in Table 7.2-25). The steam costs were adjusted based on the cost of natural gas. The capital cost and fixed operating costs were increased by 8% to reflect inflation from 1998 to 2001.

We also adjusted the capacity of the hydrogen plant to reflect the capacity which would be typical for each PADD. The hydrogen plant capacity for PADD 3 represents the average of the existing hydrogen plants in the PADD and several third party units producing 100 million scf/day of hydrogen. For other PADDs, the average plant size was based on the average of refinery-based hydrogen plants within that PADD, obtained from the Oil and Gas Journal.[41] We incorporated PADD-specific offsite and construction location factors from Table 7.2-23, again assuming a 50-50 mix of new and revamped units. Table 7.2-27 summarizes the average plant size and the offsite and location factors for the installation of hydrogen plant capital for each PADD.

Table 7.2-27
Summary of Capital Cost Factors used for Estimating Hydrogen Costs by PADD

PADD	Capacity (million scf/day)	Offsite Factor	Construction Location Factor
1	15	1.19	1.5
2	34	1.19	1.3
3	65	1.15	1.0
4	19	1.38	1.4
5 Excluding CA and AK	15	1.23	1.2
Alaska	15	1.23	2.0

The adjusted hydrogen costs in each PADD are summarized in Table 7.2-28.

Table 7.2-28
Estimated Hydrogen Costs by PADD

PADD	Cost ($/1000 scf)
1	3.26
2	2.80
3	1.89
4	2.82
5 Excluding CA and AK	2.91
AK	3.69

7.2.1.4.5 Other Operating Cost Factors

Similar to the 15% contingency factor for capital costs, we included a 10% contingency factor to account for operating costs which are beyond the those directly related to operating the desulfurization unit.[42] This factor accounts for the operating cost of processing additional hydrogen sulfide in the amine plant, additional sulfur in the sulfur plant, and other costs which may be incurred but not explicitly accounted for in our cost analysis. We then increased this factor by 2% to account for reprocessing of off-specification material. Above, we estimated that 5% of all batches could require re-processing. However, since this material would have been desulfurized to a level close to the 15 ppm cap, the operating costs for reprocessing it should be much lower the second time around.

We also believe that refinery managers will have to place a greater emphasis on the proper operation of other units within their refineries, not just the new diesel fuel desulfurization unit, to consistently deliver diesel fuel under the proposed standards. For example, meeting a stringent sulfur requirement will require that the existing diesel hydrotreater and hydrocracker units operate as expected. Also, the purity and volume of hydrogen coming off the reformer and the hydrogen plant would be important for effective desulfurization. Finally, the main fractionator of the FCC unit would have to be carefully controlled to avoid significant increases in the distillation endpoint, as this could increase the amount of sterically hindered compounds sent to the diesel hydrotreater.

Improved control each of these units could involve enhancements to computer control systems, as well as improved maintenance practices.[43] Refiners may be able to recoup some or all of these costs through improved throughput. However, even if they cannot do so, these costs are expected to be less than 1% of those estimated below for diesel fuel desulfurization.[44] [45] No costs were included in the cost analysis for these potential issues.

7.2.1.5 How Refiners are Expected to Meet the Nonroad Sulfur Requirements

This section presents the methodology used to determine which refiners produce 15 and 500 ppm highway diesel fuel, 500 ppm NRLM diesel fuel, 15 ppm nonroad diesel fuel and heating oil during the four phases of the highway and NRLM diesel fuel programs. These four phases are:

1) June 1, 2006 - May 31, 2007: 15 ppm highway cap with temporary compliance option and small refiner provisions; no NRLM caps

2) June 1, 2007- May 31, 2010: 15 ppm highway cap with temporary compliance option and small refiner provisions; 500 ppm NRLM cap with small refiner provisions

3) June 1, 2010 - May 31, 2014: 15 ppm highway cap; 15 ppm nonroad cap with small refiner provisions; 500 ppm locomotive/marine cap

4) June 1, 2014 and beyond: 15 ppm highway cap; 15 ppm nonroad cap; 500 ppm locomotive/marine cap

As can be seen from these phases, there is significant overlap between the highway and NRLM diesel fuel sulfur programs. Thus, we begin our analysis below with a projection of which refiners would likely produce 15 ppm highway diesel fuel, first in 2006 and then in 2010. Then, we project which refiners would invest to produce 500 ppm NRLM diesel fuel and then 15 ppm nonroad diesel fuel.

In order to make these projections, we estimated how much highway and NRLM diesel fuel each refiner could produce. We obtained each U.S. refinery's actual production volumes of low-sulfur (highway) and high sulfur distillate during 2000 from the Energy Information Administration (EIA). Since the highway and NRLM diesel fuel programs phase in from 2006-2010, we projected these 2000 production volumes out to 2008, the mid-point of this time period. All the costs developed below presume economies of scale projected to exist in 2008.

Over the past 20 years, the production capacity of refineries which have remained in operation has steadily increased. EIA projects that this is likely to continue. Ideally, we would project each refinery's individual growth in production between 2000 and 2008. However, this information in not available. Therefore, we projected national average growth rates for highway and high sulfur distillate fuel, respectively. This appears to be quite reasonable. Not every refinery has increased capacity, nor has the increase been the same for every refinery showing an increase. However, a comparison of the crude oil distillation capacities of refineries in 1990 and 2002 indicate that a large majority of refineries have increased capacity. Thus, projecting the same growth rate for all refiners is reasonably consistent with past growth.

We projected growth in domestic refineries' production of diesel fuel based on growth in diesel fuel consumption. Based on the demand for low and high sulfur distillate fuel in 2000 and 2008 (discussed in Section 7.1 above), we determined that, absent this rule, the demand for highway diesel fuel and high sulfur distillate would increased by 24% and 8% between 2000 and 2008. Thus, the production volume of highway diesel fuel by each domestic refinery in 2000, from EIA, was increased by 24%, and that for high sulfur distillate was increased by 8%. This implicitly assumes that imports of both fuels will remain a constant percentage of total demand.

We made no changes in the production volumes of distillate fuel to account for any reduction in wintertime blending of kerosene that might occur with the implementation of 15 ppm highway or NRLM sulfur caps. Kerosene added to 15 ppm diesel fuel must itself meet a 15 ppm sulfur. Sometimes, kerosene is added at the refinery and the winterized diesel fuel is sold or shipped directly from the refinery. At other times, the kerosene blending is done at the terminal, downstream of the refinery. The former approach could mean adding kerosene to more diesel fuel than actual requires it. The latter approach would require that a distinct 15 ppm kerosene grade be produced and distributed. Much of this 15 ppm kerosene might be used in applications not requiring 15 ppm sulfur content. Adding pour point depressant is an alternative to blending kerosene. This can be done very flexibly at the terminals in areas facing very cold weather. Thus, we expect that the use of pour point depressants will increase and the terminal blending of kerosene will decrease. For kerosene blended into winter diesel fuel, the refinery could simply be added to the distillate being fed to the hydrotreater and desulfurized along with the rest of the 15 ppm diesel fuel pool.

The current amount of terminal blending of kerosene is difficult to estimate. Therefore, we have not attempted to estimate its current or future level and account for any change in this practice. In either case (terminal kerosene blending or the use of additives), the volume of distillate provided to terminals is roughly the same. Thus, we have simply based our projected costs of today’s proposal on current diesel fuel demand. This way, we are assured of including the cost of desulfurizing the total volume of diesel fuel consumed in NRLM diesel engines. The most important assumption here is that we have assumed that a separate, 15 ppm grade of kerosene will not be produced and distributed for downstream blending. This would entail additional production and distribution costs, which we believe will discourage this practice. Thus, we have not included these costs here.

The remainder of this section provides an overview of how we projected which refineries would likely produce highway and NRLM diesel fuel during the various phases of the program and how they would likely try to optimize the construction of their desulfurization equipment in order to comply with both programs.

7.2.1.5.1 Complying with the Highway Diesel Fuel Sulfur Program

The 15 ppm cap on highway diesel fuel takes effect June 1, 2006, when 80% of the highway diesel fuel produced by non-small refiners must meet this standard. Twenty percent of highway diesel fuel can remain at 500 ppm sulfur. Small refiners, which produce roughly 5 percent of highway diesel fuel are allowed to continue producing 500 ppm highway diesel fuel until January 1, 2010. Credits for over-production of 15 ppm diesel fuel can be traded within the PADD they are generated. These credits can be used through May 31, 2010. Thus, roughly 25% of highway diesel fuel can remain at 500 ppm sulfur through May 31, 2010.

The implementation date of the 15 ppm highway diesel fuel, June 1, 2006, occurs only 3 years from now. By the time that this proposal is finalized, only slightly more than two years will remain before June 1, 2006. This leadtime is not likely to be sufficient for refiners planning on producing 15 ppm highway diesel fuel in 2006 to fully coordinate these plans with this NRLM rule. Thus, as described below, we generally made the conservative assumption that refiners would make their plans for 2006 independent of the proposed NRLM diesel fuel program. However, as indicated above, many refineries could delay the production of 15 ppm highway diesel fuel until 2010 by purchasing credits. This would give them four additional years of leadtime and allow them to fully coordinate their plans for desulfurizing both highway and NRLM diesel fuel. Therefore, we have incorporated such coordination in our projections below.

As mentioned above, small refiners are allowed to continue producing 500 ppm highway diesel fuel until 2010 without the need to purchase credits. In addition, if a small refiner chooses to meet the 15 ppm cap with their highway diesel fuel, they are allowed to produce gasoline under their interim Tier 2 sulfur standards before the final 30 ppm Tier 2 standard applies. Other refineries located in the Geographic Phase-in Area (GPA) also have this option under the 2007 highway diesel fuel program.

Small and GPA refiners have already indicated to EPA whether they plan to take this option. This information was incorporated into our analysis by projecting that these refiners would begin producing 15 ppm highway diesel fuel in 2006, as opposed to 2010.

In order to produce 15 ppm highway diesel fuel, refiners have the choice of revamping their existing distillate hydrotreater or construct a new, grassroots hydrotreater. In the 2007 highway diesel fuel rule, we projected that 80% of the volume of 15 ppm fuel would be produced using revamped hydrotreaters and 20% would be produced using new, grassroots hydrotreaters. We have retained this projection in this analysis. As described in Chapter 5, refiners are still in the process of determining how they will produce 15 ppm highway diesel fuel and revamping their existing hydrotreater still appears likely to be feasible for most refiners.

A refiner’s decision to revamp or construct a new unit will depend on many factors specific to that refinery. We lack the information necessary to project which decision individual refineries will make. Thus, we projected the cost of producing 15 ppm highway diesel fuel at each refinery using both a revamped hydrotreater and using a new, grass roots unit. An average cost was determined by weighting the revamp cost by 80% and the grass roots cost by 20%. As described in more detail in Section 7.2.2 below, we then used these average highway diesel fuel costs to determine which refineries were most likely to produce 15 ppm diesel fuel in 2006 and 2010.

The use of advanced desulfurization technologies was estimated in the same way. We made no attempt to determine which specific refineries would use each technology. We estimated the cost of producing 15 ppm diesel fuel using each technology at each refinery and then weighted these costs by the projected mix of desulfurization technologies applicable in that year.

For 2006, we assumed that refiners would only process their current highway diesel fuel volume (grown to 2008 production levels) to 15 ppm. In other words, no 15 ppm highway diesel fuel would be produced from current high sulfur distillate. However, for 2010, we evaluated the production of allowed 15 ppm highway diesel fuel from current high sulfur distillate. This could be at a refinery currently producing a mix of highway and high sulfur distillate, or just high sulfur distillate. This was done because some refineries currently produce very small quantities of highway diesel fuel, likely from naturally, low sulfur blendstocks. These refiners are unlikely to produce 15 ppm diesel fuel at such low volumes. Conversely, some refineries produce very large volumes of high sulfur distillate which could be controlled to 15 ppm with good economies of scale.

Once we had estimated each refinery's cost to produce 15 ppm highway diesel fuel, we assumed that those with the lowest cost in each PADD would be the most likely to produce this fuel in 2006. Thus, after considering the production of 15 ppm fuel by small and GPA refiners choosing to delay compliance with the Tier 2 gasoline sulfur standards, we fulfilled the remainder of each PADD's highway diesel fuel demand with 15 ppm highway diesel fuel from the other refineries, starting with those with the lowest cost per gallon and moving up until demand was met. Then in 2010, the remainder of highway diesel fuel demand was met by the next lowest cost production, either from current highway diesel fuel or high sulfur distillate fuel.

7.2.1.5.2 Complying with the 500 ppm NRLM Diesel Fuel Sulfur Standard in 2007

We used two basic criteria to project which refineries would likely produce 500 ppm NRLM diesel fuel in 2007. The first criterion was the refinery's ability to continue to sell high sulfur distillate. The Northeast has a large heating oil market. Thus, PADD 1 refineries were assumed to be able to continue to sell high sulfur distillate to this market if they desired. The same flexibility was assumed to apply to PADD 3 refineries which are either connected to one of the two large pipelines running from the Gulf Coast to the Northeast (Plantation and Colonial) or have access to ocean transport. Selected markets in PADD 5, such as Hawaii, also have significant heating oil demand, so some PADD 5 refineries were also assumed to have the flexibility to continue producing high sulfur distillate if they desired. Besides these refineries, however, all refineries in PADDs 2 and 4 and those in PADDs 3 and 5 not meeting the above criteria were assumed to have to produce 500 ppm NRLM diesel fuel starting June 1, 2007. While the proposed rule would not directly require this, we believe that for cost estimation purposes, this is a reasonable assumption.

Under the proposed NRLM diesel fuel program small refiners could continue selling high sulfur NRLM diesel fuel until June 1, 2010. Thus, these small refiners have more flexibility in selling high sulfur distillate fuel, as they can sell this fuel to either the heating oil or NRLM diesel fuel markets. We evaluated small refiners' ability to distribute high sulfur NRLM diesel fuel, as it is unlikely that common carrier pipelines would carry this fuel. Starting with the demand for NRLM diesel fuel in each PADD in 2008 from Section 7.1 above, we divided this demand by the square milage of each PADD to estimate an NRLM diesel fuel demand per square mile. We then determined the area over which each small refiner would have to distribute its high sulfur NRLM fuel in order to maintain its current production level. In all cases, assuming a circular shaped area, the radius of the circle was 100 miles or less. As this is easily within trucking distance, it was reasonable to assume that all small refiners could continue selling all of their high sulfur distillate fuel as either high sulfur distillate fuel or heating oil and delay producing any 500 ppm NRLM diesel fuel until 2010 at the earliest.

Table 7.2-29 compares the the number of refineries projected to have no choice but to produce 500 ppm NRLM diesel fuel to the number of refineries currently producing high sulfue distillate fuel.

Table 7.2-29
Number of Refineries Assumed to Have to Produce 500 ppm NRLM Diesel Fuel in 2007

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Having to Participate	1	23	11	8	10
Total Producing High Sulfur Distillate Fuel Today	13	23	41	8	20

For each PADD, we then added the production volumes of those refineries projected to have no choice but to produce 500 ppm NRLM diesel fuel to the volume of high sulfur NRLM diesel fuel which could be produced small refiners. We then compared these initial volumes of NRLM diesel fuel to the projected demand for NRLM diesel fuel in each PADD, as estimated in Section 7.1 above. We found that the demand for NRLM diesel fuel in PADDs 2 and 4 were already fulfilled by these refineries. This is not surprising given the assumptions described above. However, greater production of NRLM diesel fuel was required in PADDs 1, 3 and 5. This NRLM fuel would have to meet the proposed 500 ppm cap. We projected the refineries most likely to produce this fuel would be those facing the lowest per gallon desulfurization costs in each PADD.

All 500 ppm NRLM diesel fuel was assumed to be produced using conventional hydrotreating technology. The operating cost of this desulfurization is simply a function of the composition of each refinery's high sulfur distillate fuel, as well as some costs which vary by PADD, such as hydrogen, utilities, etc. However, a number of ways existed to estimate the capital cost, depending on how the potential production of 15 ppm diesel fuel in the future was considered and whether the refinery was already producing some of its distillate fuel as 500 ppm highway diesel fuel. The methodology used to estimate capital costs is summarized below.

As mentioned above, we generally presume that refiners projected to produce 15 ppm highway diesel fuel in 2006 cannot incorporate the production of 500 ppm or 15 ppm NRLM diesel fuel into their 2006 plans. Thus, with two exceptions, these refiners would have to construct a new, grass roots hydrotreater to produce 500 ppm NRLM in 2007.

One exception applied to refineries which produce only a very small amount of high sulfur distillate fuel compared to their volume of highway diesel fuel. This small volume is likely either off-specification diesel fuel or opportunistic sales to the non-highway diesel fuel market because of advantageous prices. Thus, in the cases where high sulfur distillate production represented 5% or less of total distillate fuel production, we assumed that the refinery could incorporate the high sulfur distillate into its highway hydrotreater design. The incremental capital cost assigned to the NRLM diesel fuel program was assumed to be the difference between the capital cost associated with a hydrotreater sized to process all the refinery's distillate fuel and that for a hydrotreater sized to treat just the highway diesel fuel volume. In this case, both hydrotreaters were assumed to be grass roots hydrotreaters. In other words, even if the high sulfur distillate fuel was being incorporated into a revamp of an existing highway diesel fuel hydrotreater, the incremental cost of increasing capacity was assumed to occur at a grass roots cost. As mentioned above, the operating cost was simply estimated based on the particular mix of blendstocks for that refinery and its location (i.e., PADD). As described above in subsection 7.2.1.2, this operating cost depends on how much of that refinery's high sulfur distillate is already being processed by a hydrotreater. Based on API/NPRA survey findings, refineries which currently have diesel fuel hydrotreaters were projected to blend a certain amount of hydrotreated material into their nonroad pool. This reduces the net hydrotreating cost, as the olefins and some polynuclear aromatics in the high sulfur distillate are already being saturated today.

The other exception is a refinery which is projected to construct a new, grass roots hydrotreater in 2006 to produce 15 ppm highway diesel fuel. This refinery would be able to produce 500 ppm NRLM fuel in 2007 with its existing highway unit. As mentioned above, we do not identify which individual refineries would likely construct a new grassroots unit in 2006. Thus, we simply assumed that 20% of the high sulfur distillate volume being produced from refineries projected to produce 15 ppm highway diesel fuel in 2006 could be desulfurized to 500 ppm with no capital costs.

The next set of refineries to be discussed are those which currently produce both highway and high sulfur distillate fuel and are not projected to produce 15 ppm highway diesel fuel until 2010. We presume that these refineries would have to build a new hydrotreater in 2007 in order to desulfurize their current high sulfur distillate to 500 ppm. However, due to the significant amount of leadtime available, we project that these refiners could design a revamp that would desulfurize all of their distillate fuel to 15 ppm in 2010 if they so desire.

Of course, refineries which only produce high sulfur distillate fuel today would have to install a new hydrotreater to produce 500 ppm NRLM fuel in 2007. We presume that this unit could be revamped in 2010 to produce 15 ppm nonroad diesel fuel in 2010, if so desired.

Table 7.2-30 presents the percentages of high sulfur distillate fuel production which falls in the categories described above.

Table 7.2-30
Production of High Sulfur Distillate: Interaction with Highway Diesel Fuel Program (%) [a]

	High Sulfur Refineries		Mixed Refineries Producing 15 ppm Highway Fuel in 2006		Mixed Refineries Producing 15 ppm Highway in 2010		Highway Refineries	
	W/Dist HT	No Dist HT	W/Dist HT	No Dist HT	W/Dist HT	No Dist HT	W/Dist HT	No Dist HT
Number of Refineries	5	20	27	8	15	13	15	2
Percent of Nonroad Fuel	22	18	32	6	13	7	2	0

[a] “Highway” refinery: high sulfur distillate fuel production ≤5% of total distillate fuel production
“High sulfur” refinery: high sulfur distillate fuel production ≥ 90% of total distillate fuel production
“Mixed refinery: refineries which are neither highway or high sulfur refineries
“ W/Dist HT” means refineries currently having a distillate hydrotreater
“No Dist HT means refineries which do not currently have a distillate hydrotreater

Table 7.2-31 presents the estimation of the volume of NRLM diesel fuel which must be desulfurized to 500 ppm in 2007 in each PADD. PADDs 1 and 3 are shown combined since we assume that PADD 3 refineries can produce and ship 500 ppm NRLM fuel to PADD 1. The first line shows total volume of NRLM diesel fuel demand from Section 7.1. The next line shows the projected volume of highway fuel spillover to the NRLM fuel pool. This volume is subtracted from NRLM demand, as the spillover already meets the proposed 500 ppm cap. The difference is total demand for high sulfur NRLM diesel fuel, which is shown on the third line. The fourth line shows total small refiner volume, which does not need to be desulfurized in 2007. Then, current production volumes of high sulfur distillate from refineries which we project would not be able to continue marketing high sulfur distillate are shown. The difference, if any, is the final volume of 500 ppm NRLM diesel fuel which must be desulfurized. We presume that this final volume would be produced by refiners facing the lowest desulfurization costs in each PADD. In PADDs 2 and 4, this last volume is zero, because we project that all refineries in these PADDs would likely have to desulfurize their high sulfur distillate to 500 ppm in order to market it. The total volume of the last two rows of the table (highlighted in bold) yields the estimated total amount of high sulfur distillate which is expected to be hydrotreated to meet the 500 ppm NRLM diesel fuel in 2007. In PADD 2 and 4, this value is larger than the required volume. Thus, some volume of heating oil is being desulfurized in these PADDs to 500 ppm.

Table 7.2-31
NRLM Diesel Fuel Volume Needing Desulfurization: 2007-2010[a] (million gallons per year)

	PADDs 1 & 3	PADD 2	PADD 4	PADD 5
NRLM Diesel Fuel Demand	7143	5111	1173	937
Highway Spillover	1709	1728	779	215
Base High Sulfur NRLM Demand	5434	3382	394	722
Small Refiner Volume	490	369	10	202
Non-Small High Sulfur Demand	4944	3013	384	519
Non-Small Volume Required to Produce 500 ppm NRLM Fuel	**914**	**3385**	**488**	**84**
Remaining Demand for 500 ppm NRLM Diesel Fuel	**4030**	**0**	**0**	**435**

[a] Based on projected volumes for 2008

Table 7.2-32 presents an analogous set of volumes for 2010 assuming that no 15 ppm nonroad diesel fuel cap was implemented. (This situation is analyzed to allow the long-term analysis of the 500 ppm NRLM diesel fuel cap independent of the 15 ppm nonroad diesel fuel cap). The primary difference is the absence of the small refiner volume.

Table 7.2-32
NRLM Diesel Fuel Volume Needing Desulfurization in the Absence of a 15 ppm Nonroad Diesel Fuel Cap: 2010 and beyond[a] (million gallons per year)

	PADDs 1 & 3	PADD 2	PADD 4	PADD 5
NRLM Diesel Fuel Demand	7,143	5,111	1,173	937
Highway Spillover	1,709	1,728	779	215
Base High Sulfur NRLM Demand	5,434	3,382	394	722
Small Refiner Volume	0	0	0	0
Net High Sulfur Volume	5,434	3,382	394	722
Non-Small Volume Required to Produce 500 ppm NRLM Fuel	**1,344**	**3,755**	**498**	**286**
Remaining Demand for 500 ppm NRLM Diesel Fuel	**4,090**	**0**	**0**	**435**

[a] Based on projected volumes for 2008

In Table 7.2-33, the refineries which are projected to produce 500 ppm NRLM diesel fuel after the program is fully phased in are characterized by whether they produce predominantly high sulfur distillate, a mix of highway and high sulfur distillate or predominantly highway diesel fuel. Like Table 7.2-32, Table 7.2-33 is provided to enable the long-term evaluation of the 500 ppm NRLM standard in the absence of the 15 ppm nonroad diesel fuel cap.

Table 7.2-33
Characterization of the Refineries Projected to Produce 500 ppm NRLM Fuel for 2007

	Nonroad Only Refineries		Mixed Refineries Complying with Highway in 2006		Mixed Refineries Complying with Highway in 2010		Highway Only Refineries	
	W/Dist HT	No Dist Ht	W/Dist HT	No Dist Ht	W/Dist HT	No Dist Ht	W/Dist HT	No Dist Ht
Number of Refineries	0	14	15	4	10	9	10	0

7.2.1.5.3 Complying with the 15 ppm Nonroad Sulfur Standard for 2010

We followed the same basic methodology for projecting the cost of 15 ppm nonroad diesel fuel in 2010, as was described in the previous section for the production of 500 ppm NRLM diesel fuel in 2007. We first considered whether refineries projected to produce 500 ppm NRLM diesel fuel in 2007 could continue to do so in 2010 if they so desired. A few refineries were found to have a sufficiently large volume of 500 ppm NRLM diesel fuel in 2007 and were located distant from a pipeline or a navigable waterway that it was deemed unlikely that they could sell all of this fuel to the locomotive and marine diesel fuel markets. These refineries were assumed to have to process this fuel further to 15 ppm.

All other refineries which produced 500 ppm NRLM diesel fuel in 2007 were assumed to have the option of producing 15 ppm nonroad diesel fuel in 2010 or continuing their production of 500 ppm fuel for the locomotive and marine diesel fuel markets. Refineries which did not produce 500 ppm NRLM diesel fuel in 2007 (or 2010 after the expiration of small refiner provisions) were not considered likely to produce 15 ppm nonroad fuel in 2010 (or 2014 after the expiration of small refiner provisions). Since the locomotive and marine diesel fuel markets exist essentially everywhere in the country, far fewer refineries were projected to have to produce 15 ppm nonroad fuel in 2010 compared to 500 ppm NRLM fuel in 2007.

Again, we evaluated small refiners' ability to market 500 ppm NRLM fuel in 2010 and found that they could do so by truck. Thus, we assumed that they would either do so or would produce 15 ppm fuel and sell credits to other refiners. In either case, their current high sulfur distillate production volume would only have to meet a 500 ppm cap in 2010. Table 7.2-34 shows the number of refineries projected to have little flexibility to avoid producing 15 ppm nonroad diesel fuel in 2010.

Table 7.2-34
Number of Refineries Assumed to Have to Produce 15 ppm Nonroad Diesel Fuel in 2010

	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
Having to Participate	1	8	0	4	5
Total Producing High Sulfur Distillate Today	13	23	41	8	17

As already described in the previous section, the capital cost for producing 15 ppm nonroad diesel fuel depends on whether the refinery currently produces highway diesel fuel and when it is projected to first produce 15 ppm diesel fuel. Refineries producing less than 5% of their distillate as high sulfur were assumed to process all their distillate in one desulfurization unit, regardless of whether this was a new unit or a revamp, whether it was first produced in 2006 or 2010.

As mentioned above, 20% of the refineries producing 15 ppm highway diesel fuel were presumed to install a new, grass roots unit to do so. These new units would desulfurize high sulfur distillate now being desulfurized to 500 ppm down to 15 ppm. These refineries could therefore produce 500 ppm NRLM diesel fuel using their existing highway diesel fuel hydrotreater. In order to produce 15 ppm nonroad diesel fuel in 2010, we assumed that these refineries would need to construct a grass roots desulfurization unit. Since the highway hydrotreater could not be revamped in 2006 in order to produce 15 ppm highway diesel fuel, it could also not be revamped to produce 15 ppm nonroad diesel fuel. We also assume that any new hydrotreater constructed in 2007 could be revamped to produce 15 ppm nonroad diesel fuel in 2010, due to its recent construction and the presumption that refiners would consider the 15 ppm cap when designing their 2007 unit.

Otherwise, the projection of the types of units that could be installed to produce 15 ppm nonroad units was consistent with the description presented in the previous section. Refineries only producing high sulfur distillate today could revamp the hydrotreater added in 2007 to produce 15 ppm nonroad diesel fuel. Refineries producing less than 5% of their distillate fuel as high sulfur fuel and projected to produce 15 ppm highway fuel in 2010 were assumed to be able to revamp their highway unit, allowing them to process the small amount of high sulfur distillate fuel in the same unit. Refineries producing both highway and high sulfur distillate today and projected to produce 15 ppm highway diesel fuel in 2010 were assumed to be able to process all their distillate to 15 ppm in a single unit (80% revamped, 20% grass roots).

The methodology for estimating the capital costs for the mixed refineries is somewhat complex. Table 7.2-34b shows a description of the different new and revamp unit options to enable refiners to meet the 15 ppm highway and nonroad standards.

Table 7.2-34b
Summary of New and Revamp Options by Refinery Situation

New vs Revamp	Refinery Configuration	Fuel Category	Type of Added Unit
Revamped Highway Hydrotreater in 2010	Refinery with Distillate Hydrotreater	Highway	Revamp of Existing Highway Hydrotreater
		Non-Highway treated in Hwy Hydrotreater	Revamped Treater
		Non-Highway	Revamp of Hydrotreater installed in 2007
	Refinery w/o Distillate Hydrotreater	Highway	Revamp of Existing Highway Hydrotreater
		Non-Highway	Revamp of Hydrotreater installed in 2007
New Highway Hydrotreater added in 2010	Refinery with Distillate Hydrotreater	Highway	New Hydrotreater
		Non-Highway treated in Hwy Hydrotreater	New Hydrotreater
		Non-Highway	Revamp of Hydrotreater installed in 2007
	Refinery w/o Distillate Hydrotreater	Highway	New Treater
		Non-Highway	Revamp of Hydrotreater installed in 2007

An example is provided here to better explain the capital cost calculation methodology. This example is made for a refinery on the Gulf Coast with a distillate hydrotreater and this refinery will comply with the highway diesel sulfur program in 2010 and also comply with the nonroad diesel fuel sulfur program in 2010. This refinery also has an FCC unit and a hydrocracker which is large enough to process all the LCO from the FCC unit. Thus, the highway and nonhighway pools would be composed of straight run diesel fuel only. The refinery produces 40,000 bbl/day of highway diesel fuel and 20,000 bbl/day of nonhighway distillate, and the hydrocracker produces 15,000 bbl/day of hydrocracked distillate, 10,000 bbl of which goes into the highway pool and 5,000 bbl of which goes into the nonhighway pool. This refinery is presumed to use the Linde hydrotreating technology to comply with the 2010 standards. As shown in Table 7.2-21, refineries with distillate hydrotreaters on the Gulf Coast are presumed to hydrotreat 44 percent of their nonhighway distillate. Thus, 44 percent of the 15,000 bbl per day nonhighway pool (20,000 bbl/day total nonhighway volume minus the 5000 bbl/day which is hydrocracked), or 6600 bbl/day is already hydrotreated, while 8400 bbl/day is not hydrotreated. Thus to calculate the capital cost for the highway and nonroad programs the following apply:

The capital cost of the highway hydrotreater is estimated using an exponential equation termed the “six-tenths rule” (from Subsection 7.2.1.4.1 above). The equation is as follows:

$(Sb/Sa)^{e}xCa=Cb$,
Sa is the size of unit quoted by the vendor,
Sb is the size of the unit for which the cost is desired,
e is the exponent, which is 0.65 for desulfurization units
Ca is the cost of the unit quoted by the vendor (which is 25000 bbl/day), and
Cb is the desired cost for the different sized unit.

The cost of the highway hydrotreater would therefore be calculated to be

$(30{,}000/25{,}000)^{0.65}$ x \$21 million = \$23.6 million
This value needs to be increased by a factor of 1.2 to account for the offsites, and for the location, which is 1.0 for the Gulf Coast (from Subsection 7.2.1.4.1 above).

This increases the highway diesel fuel hydrotreater cost to \$28.4 million.

If the highway hydrotreater were to be revamped, it would cost \$13.1 million using the same methodology but substituting a \$10.6 million figure for the base unit with a 25,000 bbl/day capacity for the \$21 million figure and using a 1.1 factor for offsites instead of 1.2. Although calculating the revamped cost seems irrelevant for this example, this value is actually used as described below.

The cost for complying with the Nonroad Program is calculating by calculating the combined Nonroad/Highway capital cost and subtracting the highway program capital cost from it. Thus, using the same equation, the cost for the combined new Nonroad/Highway hydrotreater is calcualated as follows:

$(45{,}000/25{,}000)^{0.65}$ x \$21 million = Cb which is \$30.8 million which increases to \$36.9 using the offsite factor (1.2).

To calculate the capital cost of a new Nonroad unit, the new Highway unit capital cost is subtracted from the combined, new Highway/Nonroad capital cost (\$36.9 - \$23.6 to yield the Nonroad new unit capital cost which is \$13.3. (The economy of scale benefit is apparent by calculating the capital cost of a dedicated new, nonroad only unit which is \$18.1 million and comparing it to the \$13.3 million figure.)

However, a portion of nonhighway distillate which is being desulfurized down to 500 ppm in 2007 only needs to be revamped. A credit is claimed for this fraction by calculating the economy of scale capital cost for a revamped unit and ratio the two costs.

A combined Highway/Nonroad revamped unit is calculated as follows

$(45{,}000/25{,}000)^{0.65}$ x \$10.6 million x 1.1 = \$17.1 million, then the Nonroad portion is calculated by subtracting the revamped highway hydrotreater capital cost (\$17.1 million - \$13.1 million) which is \$4.0 million.

The Nonroad capital cost is calculating by apportioning the capital cost estimates for to the respective portions of the Nonroad pool. As stated above, 44 percent of the Nonroad pool is hydrotreated and this portion requires a new unit cost while the 56 percent balance only requires the cost of a revamp. Thus, 44 percent of the capital cost is $13.3 million and 56 percent of the capital cost is $4.0 million, yielding a volume weighted cost of $8.1 million.

Table 7.2-35 presents the estimated volume of nonroad diesel fuel which must be desulfurized in 2010 to 15 ppm by PADD. The methodology used to develop these figures is the same as that described above for the required volume of 500 NRLM diesel fuel (Table 7.2-31).

Table 7.2-35
Nonroad Diesel Fuel Needing Desulfurization: 2010-2014[a]
(million gallons per year)

	PADDs 1 & 3	PADD 2	PADD 4	PADD 5
Nonroad, Diesel Fuel Demand	4440	3559	822	665
Highway Spillover	1018	1168	524	157
Base 500 ppm Nonroad Volume	3422	2391	298	508
Small Refiner Volume	407	369	10	202
Net Volume of 15 ppm Nonroad Fuel	3015	2022	288	306
Non-Small Volume Having to Produce 15 ppm Nonroad Diesel Fuel	**0**	**1032**	**370**	**84**
Remaining Demand for 15 ppm Nonroad Diesel Fuel	**3015**	**989**	**0**	**222**

[a] Based on projected volumes for 2008

Table 7.2-36 presents an analogous set of volumes for 2014. The difference is the absence of the small refiner volume.

Table 7.2-36
Nonroad Diesel Fuel Volume Needing Desulfurization: 2014 and Thereafter[a]
(million gallons per year)

	PADDs 1 & 3	PADD 2	PADD 4	PADD 5
Required Supply of Nonroad, Diesel Fuel	4,440	3,559	822	665
Highway Spillover	1,018	1,168	524	157
Net 500 ppm volume to be treated	3,422	2,391	298	508
Small Refiner Volume	0	0	0	0
Net Volume of 15 ppm Nonroad Fuel	3,422	2,391	298	508
Non-Small Volume Required to Produce 15 ppm Nonroad Diesel Fuel	**23**	**1,157**	**370**	**108**
Remaining Demand for 15 ppm Nonroad Diesel Fuel	**3,399**	**1,234**	**0**	**401**

[a] Based on projected volumes for 2008

In Table 7.2-37, the refineries which are projected to produce 15 ppm nonroad diesel fuel after the program is fully phased in are characterized by whether they produce predominantly high sulfur distillate, a mix of highway and high sulfur distillate or predominantly highway diesel fuel.

Table 7.2-37
Characterization of the Refineries Projected to Produce 15 ppm Nonroad Diesel Fuel [a]

	Nonroad Only Refineries		Mixed Refineries Complying with Highway in 2006		Mixed Refineries Complying with Highway in 2010		Highway Only Refineries	
	W/Dist HT	No Dist Ht	W/Dist HT	No Dist Ht	W/Dist HT	No Dist Ht	W/Dist HT	No Dist Ht
Number of Refineries	0	4	9	4	7	5	0	8

[ar] Refineries listed in No dist Ht column do not currently have a highway diesel hydrotreater, ie make highway fuel from straight run, hydrocrackate and other low sulfur blendstocks. These refineries would install a new hydrotreater to make 500 ppm diesel for the two step program which is revamped to make 15 ppm nonroad.

7.2.1.5.4 Projected Use of Advanced Desulfurization Technologies

In Chapter 5, we projected of the mix of technologies used to comply with a program being implemented in any year. This projection took into account the factors which affect the decisions by refiners in choosing a new technology. The projected mix of technologies for certain important years is summarized here for the reader's benefit.

Table 7.2-38
Projected Use of Advanced Desulfurization Technologies for Future Years

	2008	2009	2010	2012+
Conventional Technology	60	40	20	0
Linde Isotherming	20	30	40	50
Phillips SZorb	20	30	40	50

7.2.2 Refining Costs

In this section, we present the refining costs for the proposed NRLM diesel fuel program, as well as for several alternative fuel programs evaluated in the process of developing this proposal. The first step in developing the refining costs for the proposal was to estimate the cost of producing 500 and 15 ppm diesel fuel for each of the 143 refineries currently producing either highway diesel fuel or high sulfur diesel fuel, or both fuels. These costs were estimated for both conventional and advanced desulfurization technologies using the methodology developed in Section 7.2 above. The capital and operating cost factors for each desulfurization technology, are the same for each refinery. However, each refinery's projected 2008 production of highway diesel fuel and high sulfur distillate, its LCO fraction and other cracked stocks fraction and its location (i.e., PADD) were also used, which led to different projected costs to produce 500 and 15 ppm diesel fuel for each refinery. As the mix of desulfurization technologies is projected to vary with the implementation year for the 15 ppm standard, the cost of producing 15 ppm fuel varies with year of implementation for each refinery in the U.S.

The remainder of this section presents the refining costs for the various fuel programs. Refining costs to meet the 2007 highway diesel fuel program are presented first, as this provides the basis for evaluating the additional costs for NRLM diesel fuel sulfur control. Refining costs for the proposed two-step NRLM fuel program are presented next, followed by the refining costs for the alternative NRLM fuel programs evaluated in the developing the proposal. Finally, we present the stream of capital costs which would be required by the NRLM fuel program, in the context of other environmental requirements facing refiners in the same timeframe, namely the Tier 2 gasoline sulfur program and the 2007 highway diesel fuel program. All per gallon costs presented in this section would apply to the volume of NRLM disel fuel actually being desulfurized under the proposed fuel program. These costs would not apply to NRLM diesel fuel already meeting highway diesel fuel sulfur standards (i.e., spillover fuel).

7.2.2.1. 15 ppm Highway Diesel Fuel Program

Highway diesel desulfurization cost to15 ppm were estimated in 2006 and 2010 to provide a basis from which to estimate the costs of the NRLM program. The methodology used here is nearly identical to that used to develop the costs presented in the 2007 highway diesel fuel rulemaking. The two differences are: 1) we used more recent estimates of each refinery's current production of highway diesel fuel and high sulfur distillate, and 2) we modified the methodology used to estimate the cost of expanding the production volume of highway fuel by desulfurizing current high sulfur distillate. Both of these changes were described in Section 7.2.1 above.

We projected the specific refineries which will produce 15 ppm highway diesel fuel in 2006 based on their projected cost per gallon. We did not consider the potential for refineries to desulfurize their current high sulfur distillate fuel. The lowest cost refiners were assumed to produce 15 ppm highway diesel fuel until at least 80% of the required supply of highway diesel fuel was fulfilled. The exception to this was that several refineries with potentially higher desulfurization costs were also assumed to produce 15 ppm fuel in 2006. These refineries are eligible to select a delay in their applicable Tier 2 gasoline sulfur standards if they produce 15 ppm highway diesel fuel in 2006. Several refiners have informed EPA that they are planning to select this compliance option. Therefore, we projected that these refineries would produce 15 ppm highway diesel fuel in 2006.

We projected specific refineries to produce additional 15 ppm highway diesel fuel in 2010 again based on their projected cost per gallon. The lowest cost refiners were assumed to produce 15 ppm highway diesel fuel until at least 100% of the required supply of highway diesel fuel was fulfilled. Initially, only distillate volume which is currently highway diesel fuel was considered. After doing so, we determined that 13 refineries faced very high costs of producing 15 ppm highway diesel fuel, due solely to their extremely low production volumes and resulting poor economies of scale for a new or revamped hydrotreater. It is very likely that these refineries produce highway diesel fuel today from blendstocks which are naturally low in sulfur. It is very unlikely that they currently have a hydrotreater of such low capacity. Therefore, we do not believe that it is likely that these refineries would construct a new hydrotreater to produce such a low volume of highway fuel. Thus, we assumed that they would not produce 15 ppm highway diesel fuel in 2010. We replaced their production volume with 15 ppm diesel fuel produced from high sulfur distillate currently being produced by five refiners currently producing both highway diesel fuel and high sulfur distillate fuel.

The projected costs for producing 15 ppm highway diesel fuel are summarized in Table 7.2-39.

Table 7.2-39
Highway Diesel Desulfurization Costs to Meet a 15 ppm Cap Standard
($2002, 7% ROI before taxes)

	Refineries Producing 15 ppm in 2006	Refineries First Producing 15 ppm in 2010	All Refineries
Number of Refineries	74	40	114
Total Capital Cost ($Million)	4,210	1,240	5,450
Average Capital Cost per Refinery ($Million)	56.9	31.1	47.8
Average Operating Cost per Refinery ($Million/yr)	13.6	4.7	9.0
Total Cost (c/gal)	3.5	3.8	3.6

As can be seen, we project that 74 refineries will invest to produce 15 ppm highway fuel in 2006, with a total capital cost of $4.21 billion ($57 million per refinery). All of the fuel desulfurized to 15 ppm is produced from current highway diesel fuel. The average cost to produce 15 ppm highway diesel fuel is 3.5 cents per gallon. These costs assumed that all this 15 ppm fuel is being produced using conventional hydrotreating.

We project that 40 additional refineries will invest to produce 15 ppm highway diesel fuel in 2010, as the temporary compliance option expires. The required capital cost will be $1.24 billion ($31 million per refinery). The average cost for 15 ppm fuel newly produced in 2010 is 3.8 cents per gallon, which is 0.3 cents higher than 15 ppm fuel first produced in 2006. Five refineries invest to desulfurize both their current highway and high sulfur distillate fuels to make 15 ppm fuel, while 13 refineries cease production of highway diesel fuel.

Overall, 114 refineries produce the 15 ppm diesel fuel under the 2007 highway diesel fuel program, with a total capital cost of $5.45 billion ($47.8 million per refinery). The average refining cost in 2010 will be 3.6 cents per gallon of fuel.

7.2.2.2 Costs for Proposed Two Step Nonroad Program

The proposed two step program specifies that nonroad, locomotive and marine volumes have sulfur caps of 500 ppm in year 2007 with nonroad sulfur further reduced to 15 ppm in year 2010. Small refineries have three and four year delay provisions for complying with the 500 ppm and 15 ppm, respectively. Small refiner’s can sell high sulfur diesel fuel in the NRLM market in years 2007-2010, while small refiners can sell 500 ppm fuel in the nonroad market in years 2010-2014. In lieu of physically selling these higher sulfur fuels to the NRLM and nonroad markets, small refiners can sell their credits to other refiners, who can then do the same. From the point of view of this cost analysis, because these small refiner credits can be sold to others, the small provisions have the net result of reducing the volume of NRLM diesel fuel which would have to meet the 500 ppm cap in 2007 and the volume of nonroad diesel fuel which would have to meet the 15 ppm cap in 2010. Small refiners need not be the refiners producing the high sulfur NRLM diesel fuel in 2007-2010, nor the 500 ppm nonroad diesel fuel in 2010-2014.

Below, we first present an overall summary of the costs of the entire proposed NRLM fuel program. Then we present in greater detail the refining costs for the three steps of the proposed NRLM fuel program: 1) the 500 ppm NRLM diesel fuel cap in 2007, 2) the 15 ppm nonroad diesel fuel cap and 500 ppm locomotive and marine diesel fuel cap in 2010, and 3) the 15 ppm nonroad diesel fuel cap and 500 ppm locomotive and marine diesel fuel cap in 2014 after the expiration of small refiner provisions.

Overall, by 2014, we project that 62 refineries would invest to make either 15 or 500 ppm NRLM diesel fuel. We project that 37 of these refineries would produce 15 ppm nonroad diesel fuel, with the remaining 25 producing 500 ppm locomotive and marine diesel fuel. The projected costs to meet these standards are summarized in the two tables below. Table 7.2-40 presents the total refining costs per gallon for the various steps in and fuels of the proposed program. Table 7.2-41 presents the costs for average and small refineries.

Table 7.2-40
Number of Refineries and Refining Costs for the Proposed Two Step Program

	Year of Program	500 ppm Fuel		15 ppm Fuel	
		All Refineries[a]	Small Refineries	All Refineries[a]	Small Refineries
Number of Refineries Producing 500 or 15 ppm NRLM Diesel Fuel	2007-2010	42	0	0	0
	2010-2014	37	19	25	0
	2014+	25	12	37	7
Refining Costs (c/gal)	2007-2010	2.1	0	0	0
	2010-2014	2.3	3.3	4.2	0
	2014+	2.2	3.3	4.4	8.2

[a] Includes small refiners.

Table 7.2-41
Refining Costs for Fully Implemented (2014 and Beyond)
Proposed Two Step Program ($2002, 7% ROI before taxes)

	All Refineries	Small Refineries
Number of Refineries	62	19
Total Refinery Capital Cost ($Million)	1240	215
2007	449.0	0
2010	627.0	131.0
2014	163.0	86.0
Average Refinery Capital Cost ($Million)	20.0	11.3
Average Refinery Operating Cost ($Million/yr)	4.1	1.3

As can be seen, total capital costs would be $1,240 million for the entire proposed NRLM fuel program (average of $20.0 million per refinery). The per gallon cost of both 500 ppm and 15 ppm diesel fuels would be 2.2-2.3 and 4.2-4.4 cents, respectively. Small refiners projected to produce either 500 or 15 ppm NRLM diesel fuel would face higher costs on a per gallon basis. At the 500 ppm level, small refiner costs would be about 50% greater, at 3.3 cents per gallon. At the 15 ppm level, small refiner costs would be over 80% greater, at 8.2 cents per gallon. Total capital costs for the 19 small refineries would be $215 million (average of $11.3 million per refinery).

7.2.2.2.1 Refining Costs in Year 2007

We projected the specific refineries which would produce 500 ppm NRLM fuel beginning in 2007 in two steps. First, we identified specific refineries which would have difficulty marketing high sulfur distillate fuel in 2007 because of the small volume of heating oil sales in their PADD. These refineries were projected to hydrotreat all their high sulfur distillate fuel to 500 ppm regardless of the cost per gallon. However, we excluded small refiners in this step, as they could sell their high sulfur diesel fuel to either the NRLM diesel fuel market or the heating oil market. Second, if these refineries did not produce the required volume of 500 ppm NRLM fuel in a specific PADD, the refineries with the lowest cost of producing additional volume of 500 ppm fuel were projected to do so until sufficient 500 ppm NRLM fuel was produced in each PADD.

We project that 42 refiners would produce 500 ppm NRLM fuel in 2007. Of these 42 refineries, we project that 32 would install new hydrotreaters, seven “highway” refiners would perform a relatively minor revamp to their highway distillate hydrotreaters and three refineries could produce 500 ppm NRLM diesel fuel with an idled highway hydrotreater.[I] These last three

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[I] “Highway” refineries’ high sulfur diesel fuel production is no more than 5 percent of their total no. 2 distillate production. High sulfur refineries high sulfur diesel fuel production is no refineries were projected to build a new hydrotreater to comply with the 15 ppm highway diesel fuel standard. Therefore, their current highway hydrotreater would be available to produce 500 ppm NRLM fuel.

Small refiners were assumed to exercise small refiner delay provisions and not produce 500 ppm fuel in 2007 unless their desulfurization costs were competitive with other refiners who invested to make 500 ppm diesel fuel. However, none of the small refiners costs for producing a 15 ppm fuel were competitive with the other refineries which produced sufficient volumes of 500 ppm NRLM fuel to satisfy market demand. Thus, small refiners have no cost associated with implementing the 500 ppm standard in 2007. Small refiners would sell their high sulfur diesel fuel to the NRLM market with no attendant refining cost.

The cost of the 500 ppm NRLM cap in 2007 is summarized in Table 7.2-42 below.

Table 7.2-42
Refining Costs for 500 ppm
NRLM Diesel Fuel in 2007 ($2002, 7% ROI before taxes)[a]

	All Refineries
Number of Refineries	42
Total Refinery Capital Cost ($Million)	449
Average Refinery Capital Cost ($Million)	10.7
Average Refinery Operating Cost ($Million/yr)	3.3
Amortized Capital Cost (c/gal)	0.6
Operating Cost (c/gal)	1.5
Cost Per Affected Gallon (c/gal)	2.1

[a] With consideration of small refiner provisions.

We project that the 42 refiners would incur a total capital cost of $499 million (average of $11 million per refinery). The total refining cost for the 500 ppm NRLM diesel fuel sulfur cap is 2.1 cents per gallon of affected fuel volume, including both operating and amortized capital costs.

We repeated this 2007 analysis without the small refiner provisions (i.e., for a higher volume of 500 ppm NRLM diesel fuel. (This situation is equivalent to the proposed 500 ppm NRLM standard in 2010 without the addition of the 15 ppm nonroad diesel fuel standard). The

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less than 95 percent of their total no. 2 distillate production. All other refiners are termed mix refineries. Mix refineries projected to produce 15 ppm highway diesel fuel in 2006 and 2010 are termed 2006 mix refiners and 2010 mix refiners, respectively.

availability of this long term cost is useful in the legal justification of the 500 ppm standard.

With the expiration of the small refiner provisions regarding the 500 ppm NRLM marine diesel fuel sulfur standard, an additional 20 refiners would invest to produce 500 ppm NRLM diesel fuel, for a total of 62 refineries producing 500 ppm NRLM diesel fuel. The overall refining cost would increase very slightly to 2.2 cents per gallon. Of the 20 new refineries, 19 would be small refineries. The reason for the predominance of small refiners in this step is that most of these 19 small refiners would have difficulty marketing high sulfur distillate fuel in 2010 because of the small volume of heating oil sales in their PADD. On average, the refining cost for small refiners would be more than 60% higher than that of the non-small refiner, 3.3 cents per gallon. Various costs of the 500 ppm NRLM diesel fuel cap without the small refiner provisions are summarized in Table 7.2-43.

Table 7.2-43
Refining Costs for 500 ppm NRLM Diesel Fuel
in 2007 without Small Refiner Provisions ($2002, 7% ROI before taxes)[a]

	All Refineries	Nonsmall Refineries	Small Refineries
Number of Refineries	62	43	19
Total Refinery Capital Cost ($Million)	600	468	131
Average Refinery Capital Cost ($Million)	9.7	10.9	6.9
Average Refinery Operating Cost ($Million/yr)	2.8	3.6	0.9
Capital Cost (c/gal)	0.6	0.5	1.5
Operating Cost (c/gal)	1.6	1.5	1.8
Cost Per Affected Gallon (c/gal)	2.2	2.0	3.3

[a] Equivalent to the costs of the 500 ppm NRLM cap in 2010 without the 15 ppm nonroad cap.

7.2.2.2.2 Refining Costs in Year 2010

In 2010 under the proposal, all nonroad diesel fuel except that represented by small refiners must meet a 15 ppm cap. The specific refineries producing this 15 ppm nonroad diesel fuel were identified in a two step process, analogous to the procedure followed for 2007. First, of those refineries producing 500 ppm NRLM fuel in 2007, we identified specific refineries which would have difficulty marketing 500 ppm locomotive and marine diesel fuel in 2010 because of difficulty economically transporting this fuel in large quantities. Second, the refineries with the lowest cost of producing 15 ppm fuel were projected to do so until sufficient 15 ppm nonroad fuel was produced in each PADD.

After the refineries projected to produce 15 ppm nonroad diesel fuel in 2010 were identified, this left a few refineries still producing 500 ppm diesel fuel from those first producing 500 ppm

NRLM diesel fuel in 2007. Additional refineries were then identified in each PADD until the total production volume of 500 ppm diesel fuel reached the required volume of locomotive and marine and small refiner nonroad diesel fuel.

We project that 25 refineries would produce 15 ppm nonroad diesel fuel in 2010. Two of these refineries would install new hydrotreaters, as they were using their existing highway diesel hydrotreater to produce 500 ppm NRLM diesel fuel in 2007. Five "highway" refineries would incorporate their current high sulfur distillate fuel with their highway diesel fuel when they revamp their highway hydrotreater to produce 15 ppm highway diesel fuel in 2010. The remaining 18 refineries are projected to revamp their new nonroad hydrotreater built in 2007 to produce 500 ppm NRLM diesel fuel.

The refining costs to produce 15 ppm nonroad fuel in 2010 are presented in Table 7.2-44. The first column of costs shows the total refining cost relative to today's uncontrolled sulfur levels. The last column shows the incremental costs relative to the cost of producing 500 ppm fuel in 2007. Small refiners were assumed to exercise small refiner delay provisions and not produce 15 ppm fuel in 2010 unless their desulfurization costs were competitive with other refiners in whom invested to make 15 ppm diesel fuel. However, none of the small refiners costs for producing a 15 ppm fuel were competitive with the other refineries which produced sufficient volumes of 15 ppm nonroad fuel to satisfy market demand. Thus, small refiners are projected to have no cost associated with the 15 ppm nonroad diesel fuel standard in 2010.

Table 7.2-44
Refining Costs to Produce 15 ppm Nonroad Diesel Fuel in 2010
($2002, 7% ROI before taxes)

	All Refineries	Incremental Desulfurization Cost 500ppm to15 ppm All Refineries
Number of Refineries	25	25
Total Refinery Capital Cost ($Million)	720	477
Average Refinery Capital Cost ($Million)	28.8	19.1
Average Refinery Operating Cost ($Million/yr)	6.0	2.6
Capital Cost (c/gal)	1.5	0.9
Operating Cost (c/gal)	2.7	1.2
Cost Per Affected Gallon (c/gal)	4.2	2.1

The desulfurization equipment used to meet the 500 ppm standard would have been built three years prior, and we expect it would have been designed to facilitate further processing to 15 ppm sulfur through a revamp. However, a few refiners which were expected to use their existing highway diesel hydro treaters to meet the proposed 500 ppm cap in 2007 would likely have to construct new equipment in 2010 to meet the 15 ppm cap on nonroad diesel fuel.

We project that 25 refineries would invest to produce 15 ppm nonroad in 2010 at an incremental capital cost of $477 million. Including the cost of meeting the 500 ppm NRLM cap in 2007, these 25 refineries' total capital costs would be $720 million. The incremental cost of producing 15 ppm nonroad diesel fuel is 2.1 cents per gallon, for a total cost of 4.2 cents per gallon. The incremental cost of 2.1 cents per gallon to desulfurize 500 ppm diesel fuel to a 15 ppm cap is 1.5 cents per gallon less than the 3.6 cent per gallon cost estimated above for the 15 ppm highway diesel fuel cap. There are three reasons for this. One, most 15 ppm highway fuel is being initially produced in 2006, when we project little or no use of advanced desulfurization technologies. Two, current highway hydrotreaters are at least 10 years old. We project that only 80% of them can be revamped to produce 15 ppm diesel fuel. Thus, the cost for 15 ppm highway diesel fuel includes new hydrotreaters for 20% of the volume. However, over 90% of 500 ppm nonroad diesel fuel would be produced in 2007 using new hydrotreaters. All of these new units could be designed to be revamped in 2010. Three, we focused the production of 15 ppm highway diesel fuel to a large degree on those refiners already producing 500 ppm highway diesel fuel. This included some refiners with relatively high costs of producing 15 ppm fuel. As described above, we did exclude 13 refineries with very high costs of producing 15 ppm fuel, and replaced their highway fuel with 15 ppm fuel produced from current high sulfur distillate fuel by four selected refineries. However, we did not include a few current "high sulfur" refineries which are projected to have the lowest cost of producing 15 ppm diesel fuel from high sulfur distillate fuel. We will reconsider this decision in the analysis for the final rule, as it may have increased the projected cost of 15 ppm highway diesel fuel and lowered the cost of producing 15 ppm nonroad diesel fuel to too great a degree. However, we do not expect this change to substantially change the average costs per gallon, as the total fuel volume affected by this decision is small.

With respect to the 500 ppm locomotive and marine diesel fuel cap in 2010, we project that 20 refiners would invest in new hydrotreaters to produce 500 ppm fuel, with 19 of these being small refiners. The reason most of these additional refiners would be small refiners is due to the expiration of the small refiner provisions related to 500 ppm NRLM diesel fuel. An additional 17 refineries would continue producing 500 ppm diesel fuel (which they started doing in 2007).

The costs of producing 500 ppm diesel fuel in 2010 are presented in Table 7.2-45. This fuel includes locomotive and marine diesel fuel, as well as 500 ppm nonroad diesel fuel produced by small refiners (or by other refiners purchasing small refiner credits). Of the 20 refineries which initially comply with the 500 ppm standard in year 2010, 17 refiners would install new hydro treaters and three "highway" refiners would modify their existing highway hydrotreater to process their high sulfur distillate fuel.

Table 7.2-45
Refining Costs for 500 ppm Diesel Fuel in 2010 ($2002, 7% ROI before taxes)

	All Refineries in 2010	New Refineries in 2010	Small Refineries
Number of Refineries	37	20	19
Total Refinery Capital Cost ($Million)	357	150	131
Average Refinery Capital Cost ($Million)	9.7	7.5	6.9
Average Refinery Operating Cost ($Million/yr)	5.3	1.6	0.9
Capital Cost (c/gal)	0.7	0.8	1.5
Operating Cost (c/gal)	1.6	1.6	1.8
Cost Per Affected Gallon (c/gal)	2.3	2.4	3.3

The average cost per gallon of producing 500 ppm fuel for the 20 new 500 ppm refineries is almost identical to that for the 17 refineries already producing 500 ppm fuel. However, small refiners would face costs roughly 40% higher than those of the average refiner producing 500 ppm fuel.

7.2.2.2.3 Refining Costs in Year 2014

15 ppm Nonroad Diesel Fuel: In 2014, small refiner provisions related to the 15 ppm nonroad diesel fuel cap expire, increasing the total required volume of 15 ppm nonroad diesel fuel. The total production volume of 500 ppm NRLM diesel fuel decreases to just that used in locomotives and marine vessels. The specific refineries producing the additional volume of 15 ppm nonroad diesel fuel were those facing the lowest projected costs per gallon in each PADD, plus some refineries which we projected would have difficulty distributing large volumes of 500 ppm locomotive and marine diesel fuel. The volume of combined 15 ppm and 500 ppm NRLM fuel in 2014 is the same as that in 2010.

We project that 12 additional refineries would produce 15 ppm nonroad diesel fuel in 2014, with 7 of these being refineries owned by small refiners. None of these refineries would install new hydrotreaters, as none were using their existing highway diesel hydrotreater to produce 500 ppm NRLM diesel fuel in 2007. Three “highway” refineries would incorporate their current high sulfur distillate fuel with their highway diesel fuel when they revamp their highway hydrotreater to produce 15 ppm highway diesel fuel in 2010. The remaining 9 refineries are projected to revamp their new nonroad hydrotreater built in 2007 to produce 500 ppm NRLM diesel fuel.

The refining costs to produce 15 ppm nonroad fuel in 2014 are presented in Table 7.2-46. The first two columns containing costs show the total and incremental refining costs for all refineries. The last two columns containing costs show the total and incremental refining costs for small refiners. Total refining costs are those relative to today's uncontrolled sulfur levels. Incremental costs are those relative to the cost of producing 500 ppm fuel in 2007 or 2010.

Table 7.2-46
Refining Costs for 15 ppm Nonroad Fuel for Refiners Initially Complying in 2014
($2002, 7% ROI before taxes)

	All Refineries		Small Refineries	
	Total	Incremental to 500 ppm	Total	Incremental to 500 ppm
Number of Refineries	12	12	7	7
Total Refinery Capital Cost ($Million)	256	163	161	86
Average Refinery Capital Cost ($Million)	21.3	13.6	23.0	12.23
Average Refinery Operating Cost ($Million/yr)	2.9	1.5	2.2	0.9
Capital Cost (c/gal)	2.4	1.5	4.4	2.3
Operating Cost (c/gal)	3.0	1.5	3.8	1.1
Cost Per Affected Gallon (c/gal)	5.3	3.0	8.2	3.9

The total refining cost to produce 15 ppm fuel is 5.3 cents per gallon, or 1.1 cent per gallon more than in 2010. The average incremental cost to desulfurize from 500 ppm to 15 ppm is 3.0 cents per gallon, or 0.9 cents per gallon higher than in 2010. Small refiners' average cost to produce 15 ppm nonroad diesel fuel 8.2 cents per gallon, or more than 50% higher than that of the average refiner. The average refinery first producing 15 ppm nonroad diesel fuel in 2014 faces a capital investment of $14 million, while the investment for the average small refiner would be only slightly smaller, $12 million.

The following two tables present the total and incremental refining costs for all 15 ppm nonroad diesel fuel being produced in 2014, after the expiration small refiner provisions. These costs include those for refiners first producing 15 ppm nonroad diesel fuel in 2010 and 2014.

Table 7.2-47
Total Refinery Costs for 15 ppm Nonroad Diesel Fuel in 2014
($2002, 7% ROI before taxes)

	All Refineries	Non-small Refineries	Small Refineries
Number of Refineries	37	30	7
Total Refinery Capital Cost ($Million)	976	813	161
Average Refinery Capital Cost ($Million)	26.4	27.1	23.0
Average Refinery Operating Cost ($Million/yr)	5.0	5.7	2.2
Capital Cost (c/gal)	1.6	1.4	4.4
Operating Cost (c/gal)	2.8	2.7	3.8
Cost Per Affected Gallon (c/gal)	4.4	4.1	8.2

Table 7.2-48
Incremental Refinery Costs for All 15 ppm Nonroad Fuel in 2014
($2002, 7% ROI before taxes)

	All Refineries	Non-small Refineries	Small Refineries
Number of Refineries	37	30	7
Total Refinery Capital Cost ($Million)	640	556	84
Average Refinery Capital Cost ($Million)	17.3	18.5	11.9
Average Refinery Operating Cost ($Million/yr)	2.0	2.6	1.0
Capital Cost (c/gal)	1.1	1.0	2.3
Operating Cost (c/gal)	1.1	1.2	1.7
Cost Per Affected Gallon (c/gal)	2.3	2.2	4.0

With full implementation of the 15 ppm nonroad diesel fuel cap, we project that 37 refineries would produce this fuel. The total refining cost measured from today's high sulfur level would be 4.4 cents per gallon, or 2.3 cents per gallon cost over that to produce 500 ppm fuel. Small refineries would have an average cost of 8.2 cents per gallon, or twice as high as the average non-small refineries. The average capital cost to produce 15 ppm nonroad fuel would be $23.0 million for the average small refiner, or $4 million less than the average non-small refinery. However, the amortized capital cost per gallon would be much higher for the average small refinery due to their lower production volumes.

500 ppm Locomotive and Marine Diesel Fuel: In 2014, the number of refineries producing 500 ppm fuel drops from 37 to 25, as no new volume of 500 ppm diesel fuel would be required and 12 refineries producing 500 ppm diesel fuel in 2010 shift to 15 ppm nonroad diesel fuel.

There is no new investment to produce 500 ppm diesel fuel, as all of the 500 ppm locomotive and marine diesel fuel being produced in 2014 was already being produced in 2010. The costs of the remaining 500 ppm diesel fuel being produced in 2014 are shown in Table 7.2-49.

Table 7.2-49
Refining Costs to Produce 500 ppm Locomotive and Marine Diesel Fuel in 2014
($2002, 7% ROI before taxes)

	All Refineries	Small Refineries
Number of Refineries	25	12
Average Refinery Capital Cost ($Million)	10.6	4.5
Average Refinery Operating Cost ($Million/yr)	2.8	0.8
Capital Cost (c/gal)	0.6	1.0
Operating Cost (c/gal)	1.6	1.7
Cost Per Affected Gallon (c/gal)	2.2	2.7

The cost to produce 500 ppm diesel fuel in 2014 is 2.2 cents per gallon. This is a slight decrease from the cost in 2010 due a number of higher cost refineries (mostly owned by small refiners) exiting the 500 ppm market to make 15 ppm fuel. The average cost for small refiners still producing 500 ppm diesel fuel is only slightly greater than that for the average refinery, 2.7 cents per gallon.

7.2.2.2.4 Total Refining Costs at Different Rates of Return on Investment

We also estimated the total refining cost of the proposed NRLM fuel program using two alternative rates of return on investment: 1) 6% per year after taxes, and 2) 10% per year after taxes. The 6% rate is indicative of the economic performance of the refining industry over the past 10-15 years. The 10% rate is indicative of economic performance of an industry like refining which would attract additional capital investment. The total refining costs for both 500 and 15 ppm NRLM fuels once the proposed program is fully implemented in 2014 are shown below for our standard 7% before tax rate, and the two alternative rates. As can be seen, the difference in the rates of return on investment range from 0.1-0.8 cents per gallon.

Table 7.2-50
Total Refining Costs for the Fully Implemented Proposed NRLM Program with Different Capital Amortization Rates (cents per gallon, $2002)

	500 ppm Locomotive and Marine Diesel Fuel	15 ppm Nonroad Diesel Fuel
Societal Cost 7% ROI before Taxes	2.2	4.4
Capital Payback (6% ROI, after Taxes)	2.3	4.5
Capital Payback (10% ROI, after Taxes)	2.6	5.2

7.2.2.3 15 ppm Nonroad Diesel Fuel with Conventional Technology

The use of advanced technology is expected to reduce the cost of producing 15 ppm diesel fuel compared to conventional hydrotreating. To determine the sensitivity of our costs estimates to the level of advanced technology projected, we developed costs for producing 15 ppm nonroad diesel fuel with only the use of conventional hydrotreating.

Total refining costs to produce 15 ppm nonroad diesel fuel in 2014 are shown in Table 7.2-51. The number of refiners required to invest (37 refiners) and types of hydrotreating modifications are the same with conventional technology as described above for a mix of advanced and conventional technology. Total capital costs would be $983 million with conventional technology, essentially identical to the $976 million investment with advanced technology (see Table 7.2-40). However, operating costs would be nearly 40% higher with conventional technology, $6.9 million as compared to $5.0 million with advanced technology. The same comparison applies to the impact of advanced technology on the capital costs faced by small refiners. While the use of conventional technology increases operating costs for small refiners ($2.6 million per year versus $2.2 million per year with advanced technology), the reduction is smaller at just over 15%. This smaller benefit is due to their lower production volumes and lower fractions of LCO and other cracked stocks. The total cost to produce 15 ppm nonroad diesel fuel in 2014 with conventional technology would be 5.4 cents per gallon, versus 4.4 cents with a mix of conventional and advanced technology.

Table 7.2-51
Total Refining Costs to Produce 15 ppm Nonroad Diesel Fuel
with Conventional Technology in 2014 ($2002, 7% ROI before taxes)

	All Refineries	Small Refineries
Number of Refineries	37	7
Total Refinery Capital Cost ($Million)	983	150
Average Refinery Capital Cost ($Million)	26.6	21.5
Average Refinery Operating Cost ($Million/yr)	6.9	2.6
Capital Cost (c/gal)	1.6	4.1
Operating Cost (c/gal)	3.8	4.5
Cost Per Affected Gallon Cost (c/gal)	5.4	8.5

The previous comparisons involved the total cost of producing 15 ppm diesel fuel from high sulfur diesel fuel. However, we are only projecting that the advanced technology would be applied to the step from 500 ppm to 15 ppm sulfur. Table 7.2-52 compares the refining costs of producing 15 ppm nonroad diesel fuel from 500 ppm diesel fuel using 100 percent conventional hydrotreating and with a mix of advanced and conventional technology.

Table 7.2-52
Impact of Advanced Technology on the Incremental Refining Costs
to Produce 15 ppm Nonroad Diesel Fuel ($2002, 7% ROI before taxes)

	Refineries Producing 15 ppm Fuel First in 2010		Refineries Producing 15 ppm Fuel First in 2014	
	Advanced and Conventional	Conventional Technology Only	Advanced and Conventional	Conventional Technology Only
Average Capital Cost ($Million)	19.1	19.4	13.6	12.7
Operating Cost ($Million/yr)	2.6	5.4	1.5	2.11
Capital Cost (c/gal)	0.9	0.9	1.5	1.4
Operating Cost (c/gal)	1.2	2.5	1.5	2.1
Cost Per Gallon (c/gal)	2.1	3.4	3.0	3.5

For refiners that first produce 15 ppm nonroad diesel fuel in 2010, the projection that 80 percent would use advanced technology versus conventional technology decreases incremental refining costs relative to 500 ppm fuel by 1.4 cents per gallon, or more than 25%. Capital costs decrease only slightly, while operating costs decrease by more than 50%.

For refiners that first produce 15 ppm nonroad diesel fuel in 2014, the projection that 100 percent would use advanced technology versus conventional technology decreases incremental refining costs relative to 500 ppm fuel by 0.5 cents per gallon, or roughly 15%. Capital costs actually increase, while operating costs decrease by roughly 30%. The lower savings occurring in 2014 relative to 2010 are due to the relative volumes of distillate being desulfurized at each refinery and the percentages of LCO and other cracked stocks at the refineries producing 15 ppm fuel in the two timeframes.

7.2.2.4 Refining Costs for Alternative NRLM Fuel Programs

7.2.2.4.1 One Step NRLM Fuel Program in Year 2008

This one step program specifies that nonroad diesel fuel would have to meet a sulfur cap of 15 ppm starting on June 1, 2008, while locomotive and marine diesel fuel would have to meet a 500 ppm cap at the same time. Small refiners would have four more years before having to meet these standards. In the meantime, small refiners could sell high sulfur diesel fuel to the NRLM fuel markets.

Once fully implemented, the same refineries would produce the same 15 and 500 ppm NRLM diesel fuels as those projected under the proposed NRLM fuel program. Still, moving up the 15 ppm nonroad diesel fuel cap by two years would increase costs in two ways. One, the cost of 15 ppm nonroad fuel would be incurred two years earlier. That effect is addressed in Chapter 12, where aggregate costs are estimated for the various alternatives. Two, the cost of producing 15 ppm nonroad fuel would increase, as the earlier implementation date is projected to reduce the penetration of advanced desulfurization technology. As described in section 7.2.1 above, we project that refiners would use a mix of 60 percent conventional and 40 percent advanced technology to produce 15 ppm diesel fuel in 2008, as compared to a 20/80 mix in 2010. Fifteen ppm diesel fuel initially produced in 2012 would be desulfurized using 100 percent advanced technology, as was projected for 2014. Cost are only presented for the fully implemented program in 2012.

We project that 62 refineries would produce 500 ppm locomotive and marine diesel fuel or 15 ppm nonroad diesel fuel in 2012, when the program would be fully implemented. The total refining costs for the one step fuel program are shown in Table 7.2-53. The total refining cost for the one step fuel program for 15 ppm nonroad fuel would be 4.8 cents per gallon, or 0.4 cents per gallon more than that for nonroad fuel cost in the proposed two step program. The total capital cost of the one step program would also exceed those of the proposed two step program by $55 million.

Table 7.2-53
Total Refining Cost to Produce 15 ppm Nonroad Diesel Fuel
Under One Step Program ($2002, 7% ROI before taxes)

	One Step Program	Proposed Program
Number of Refineries	37	37
Total Refinery Capital Cost ($Million)	1,031	976
Average Refinery Capital Cost ($Million)	27.9	26.4
Average Refinery Operating Cost ($Million/yr)	5.6	5.0
Cost Per Affected Gallon Cost (c/gal)	4.8	4.4

The cost of the 500 ppm locomotive and marine diesel fuel under the one step program would not differ from that under the proposed two step program, as the same refineries using the same conventional hydrotreating are projected to be used in both cases. The difference in total costs of the two programs lies in the production of 15 ppm nonroad diesel fuel.

7.2.2.4.2 Proposed Two Step NRLM Fuel Program with Nonroad 15 ppm Cap in 2009

This program would be identical to the proposed NRLM fuel program except for one difference: the 15 ppm nonroad sulfur cap would be implemented one year earlier. The 500 ppm sulfur standard for nonroad, locomotive and marine would still begin in mid-2007. Small refiners would be able to sell high sulfur diesel fuel to the NRLM markets until mid-2009, and would be able to sell 500 ppm diesel fuel to the nonroad market until mid-2013.

Moving up the 15 ppm nonroad diesel fuel cap by one year would increase costs in two ways. One, 15 ppm nonroad fuel would be incurred one year earlier. That effect is addressed in Chapter 12, where aggregate costs are estimated for the various alternatives. Two, the cost of producing 15 ppm nonroad fuel would increase due to the earlier implementation date. The 37 refineries planning to produce 15 ppm nonroad diesel fuel in 2009 would only be producing 500 ppm NRLM fuel for two years. Thus, we projected that they would fully construct their 15 ppm desulfurization equipment in 2007. This moved up the capital needed to meet the 15 ppm cap by one year, increasing amortized costs per gallon of 15 ppm fuel produced. It also reduced the projected penetration of advanced desulfurization technology. Specifically, we project that 60% of the volume of 15 ppm fuel would be produced using advanced technology with a 2007 construction date, compared to the 80% level a year later. Small and other refiners first producing 15 ppm fuel in 2013 would be all projected to use 100 percent advanced technology.

The cost of the 500 ppm locomotive and marine diesel fuel cap would not be affected by moving up the 15 ppm cap one year, as the same refineries using conventional hydrotreating are projected to be used in both programs. The difference in total costs of the two programs lies in the production of 15 ppm nonroad diesel fuel. Thus, we have summarized the costs of producing 15 ppm nonroad diesel fuel in Table 7.2-54. Overall, the same refineries are projected to produce

15 ppm nonroad diesel fuel. While total capital costs are essentially identical, operating costs increase relative to the proposed two step program by 10% and per gallon costs increase by 5%.

Table 7.2-54
Total Refining Costs for 15 ppm Nonroad Fuel Under a
Two Step Program with the 15 ppm Standard in 2009 ($2002, 7% ROI before taxes)

	Two Step Program with 15 ppm in 2009	Proposed Two Step Program
Number of Refineries	37	37
Total Refinery Capital Cost ($Million)	977	976
Average Refinery Capital Cost ($Million)	26.4	26.4
Average Refinery Operating Cost ($Million/yr)	5.5	5
Cost Per Affected Gallon Cost (c/gal)	4.6	4.4

7.2.2.4.3 Proposed Two Step Program with a 15 ppm Cap for Locomotive and Marine Fuel in 2010

This program would be identical to the proposed NRLM fuel program except for one difference: the 15 ppm nonroad sulfur cap would be extended to locomotive and marine diesel fuel. The 500 ppm sulfur standard for nonroad, locomotive and marine would still begin in mid-2007. Small refiners would be able to sell high sulfur diesel fuel to the NRLM markets until mid-2010, and would be able to sell 500 ppm diesel fuel to the NRLM market until mid-2014.

The cost of the 500 ppm locomotive and marine diesel fuel cap in 2007 would not be affected by moving up the 15 ppm cap one year, as the same refineries using conventional hydrotreating are projected to be used in both programs. The difference in total costs of the two programs lies in the increased production of 15 ppm nonroad diesel fuel in 2010 and 2014. The total costs of producing NRLM diesel fuel for both the proposed program and that with the 15 ppm cap for locomotive and marine diesel fuel are shown in Table 7.2-55.

Table 7.2-55
Total Refining Costs for Two Step Program:
All NRLM Fuel to 15 ppm in 2010 ($2002, 7% ROI before taxes)[a]

	One Step Program	Proposed Program
Number of Refineries	62	62
Total Capital Cost ($Million)	1,720	1,240
Average Capital Cost per Refinery ($Million)	27.7	20.0
Average Refinery Operating Cost ($Million/yr)	4.9	4.1
Cost Per Affected Gallon Cost (c/gal)	4.6	4.1

[a] Fully implemented program in 2014.

Overall, the same refineries are projected to be affected. The difference is that refineries producing 500 ppm locomotive and marine diesel fuel in 2014 under the proposed program now produce 15 ppm diesel fuel. Extending the 15 ppm cap to locomotive and marine diesel fuel increases total capital cost by $480 million. The total cost per gallon of fuel affected would increase by 0.5 cent per gallon, or just over 10%. The cost of 15 ppm diesel fuel would increase from to 4.6 from 4.4 cents per gallon, or just 5%. However, this approach spreads out the increased costs of extending the 15 ppm cap to greater fuel volume of all NRLM diesel fuel volume. The cost of the 15 ppm locomotive and marine diesel fuel would be 4.8 cents per gallon, or about 10% greater than the 15 ppm nonroad diesel fuel.

7.2.2.5 Capital Investments by the Refining Industry

Refiners must raise capital to invest in new desulfurization equipment to produce the 500 ppm and 15 ppm diesel fuel which would be required under the proposed NRLM fuel program. The previous sections estimated the total capital cost associated with the proposal and two alternative programs. Refiners expend this capital over a several year period prior to the time which the new equipment must be used. This section estimates how much capital would have to be expended in specific years under the proposal and two alternative programs. These yearly expenditures are then added to those required by other fuel quality programs being implemented in the same timeframe and compared to historic capital expenditures made by the refining industry.

Two fuel quality regulations are being implemented in the same timeframe as this proposed NRLM fuel program: The Tier 2 gasoline sulfur program and the 2007 highway diesel fuel sulfur program. In the Tier 2 gasoline sulfur control rule, we estimated the expenditure of capital for gasoline desulfurization by year according to the phase in schedule promulgated in the rule.[j] The

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[J] Regulatory Impact Analysis - Control of Air Pollution from New Motor Vehicles: The Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, U.S. EPA, 2007 highway diesel rule modified that phase in schedule by provided certain refiners more time to meet the Tier 2 gasoline sulfur standards. In the 2007 highway diesel rule, we projected the stream of capital investments required by the U.S. refining industry for both the modified Tier 2 standards and the 15 ppm highway diesel fuel sulfur program. We updated the total capital costs associated with the 2007 highway diesel fuel program, as discussed in section 7.2.2.1 above. In projecting the stream of capital expended for a particular project, we assume that the capital investment would be spread evenly over a 24 month period prior to the date on which the unit must be on-stream. The stream of projected capital investment related to the Tier 2 gasoline sulfur program and the 2007 highway diesel fuel program rule are shown in Table 7.2-56.

Table 7.2-56
Capital Expenditures for Gasoline and Highway Diesel Fuel Desulfurization
($Billion, $2002)[a]

Calendar Year	Tier 2 Gasoline Sulfur Program	2007 Highway Diesel Program	Total
2002	1.76		1.76
2003	1.15		1.15
2004	0.88	1.33	2.21
2005	0.61	2.15	2.76
2006	0.16	0.82	0.98
2007	0.06		0.06
2008	0.06	0.41	0.47
2009	0.02	0.62	0.64
2010		0.21	0.21

[a] 2002 dollars obtained by use of Chemical Engineering Plant Annual Cost Index to adjust capital costs for Tier 2 gasoline program (1997 dollars) and highway diesel capital program (1999 dollars).

The two diesel fuel programs have implementation dates of June 1 of various years for fuel leaving the refinery. For this start up date, we assumed that 30% of the capital cost was expended in the calendar year two years prior to start up, 50% was expended in the year prior to start up and the remaining 20% was expended in the year of start up. We repeated this analysis for the one step NRLM program and the proposed NRLM program with 15 ppm cap for locomotive and marine diesel fuel. The results are summarized in Table 7.2-57 below.

December 1999, EPA 420-R-99-023. Adjusted to 2002 dollars using Chemical Engineering Plant Cost Index.

Table 7.2-57
Capital Expenditures for NRLM Fuel Programs with
Tier 2 Gasoline Sulfur and 2007 Highway Diesel Fuel Programs ($Billion, $2002)

Calendar Year	Proposed Two Step NRLM Fuel Program		Proposed Program + Locomotive and Marine to 15 ppm in 2010		One Step NRLM Program in 2008	
	Increment	Total[a]	Increment	Total[a]	Increment	Total[a]
2002		1.76		1.76		1.76
2003		1.15		1.15		1.15
2004		2.21		2.21		2.21
2005	0.14	2.90	0.14	2.90		2.76
2006	0.23	1.21	0.23	1.21	0.31	1.29
2007	0.09	0.15	0.09	0.15	0.52	0.58
2008	0.19	0.66	0.32	0.79	0.21	0.68
2009	0.31	0.95	0.54	1.18	0.64	0.64
2010	0.13	0.34	0.22	0.43	0.08	0.29
2011					0.13	0.13
2012	0.05	0.05	0.54	0.54	0.05	0.05
2013	0.08	0.08	0.91	0.91		
2014	0.03	0.03	0.36	0.39		

[a] 2002 dollars obtained by use of Chemical Engineering Plant Annual Cost Index to adjust capital costs for Tier 2 gasoline program (1997 dollars) and highway diesel capital program (1999 dollars).

As can be seen, capital investments peak in 2005 for all NRLM programs. The proposed two step NRLM program increases this peak by $140 million, or about 5%. Thereafter, capital requirements drop dramatically. The proposed two step NRLM program with a 15 ppm cap on locomotive and marine diesel fuel would require the same capital investments increases through 2007. Thereafter, it causes increased capital requirements, but this is well after the peak investment requirements have occurred. The one step NRLM fuel program avoids increasing capital investment in 2005, but more than makes up for this in 2006, though at a lower total investment for all three programs. In all cases, the vast majority of capital investment in the 2002-2006 timeframe, when capital investment requirements are the highest, are causes by the Tier 2 gasoline sulfur and 2007 highway diesel fuel programs. In comparison, the capital investment requirements for the proposed NRLM fuel program are much smaller and more spread out.

Estimates of previous capital investments by the oil refining industry for the purpose of environmental control are available from two sources: the Energy Information Administration

(EIA) and the American Petroleum Institute (API). According to EIA, capital investment by the 24 largest oil refiners for environmental purposes peaked at $2 billion per year during the early 1990's.[k] Total capital investment by refiners for other purposes was in the $2-3 billion per year range during this time frame. API estimates somewhat higher capital investments for environmental purposes, with peaks of about $3 billion in 1992-1993.[l] Based on these two sources, during the early 90's, the US refining industry invested over 20 billion dollars in capital for environmental controls for their refining and marketing operations, representing about one half of the total capital expenditures made by refiners for operations.

The capital required for the Tier 2 gasoline, 2007 highway diesel fuel and the proposed NRLM fuel program is about two-thirds of the historic peak level of investment for meeting environmental programs experienced during 1992-1994.[46] Given that the capital required by the proposed NRLM fuel program contributes only 5% to the required investment in the peak year of 2005, we do not expect that the industry would have difficulty raising this amount of capital.

7.2.2.6 Other Cost Estimates for Desulfurizing Highway Diesel Fuel

For the Engine Manufacturers Association and with input by the American Petroleum Institute, Mathpro used a notional refinery model to estimate the national average costs of desulfurizing nonroad diesel fuel after the implementation of the 15 ppm cap standard for highway diesel fuel. The cost estimate from this study is presented here and compared to our costs.

In a study conducted for the EMA,[4748] MathPro, Inc. first estimated the cost of desulfurizing diesel fuel to meet a 15 ppm highway diesel fuel sulfur cap standard followed by a two step nonroad standard of caps of 500 ppm and 15 ppm. MathPro assumed that desulfurization would occur entirely with conventional hydrotreating, and refining operations and costs were modeled using their ARMS modeling system with technical and cost data provided by Criterion Catalyst Company LP, Akzo-Nobel Chemicals Inc., and Haldor Topsoe, Inc. The Mathpro refinery model estimated costs based on what Mathpro terms a “notional” refinery. The notional refinery is configured to be typical of the refineries producing highway diesel fuel for PADDs 1, 2, and 3, and also represent the desulfurization cost for those three PADDs based on the inputs used in the refinery model. The Mathpro notional refinery model maintained production of highway diesel fuel at their base levels.

Mathpro made a number of estimates in their study to size their diesel desulfurization units for estimating the capital cost, and these estimates were similar to those included in our methodology. The calendar day volume was adjusted to stream day volume using a 10 percent factor to account for variances in day-to-day operations, and another 10 percent to account for

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[K] Rasmussen, Jon A., “The Impact of Environmental Compliance Costs on U.S. Refining profitability,” EIA, October 29, 1997.

[L] API Reported Refining and Marketing Capital Investment 1990-1998.

variance in seasonal demand. In addition, Mathpro applied a factor which falls somewhere in the range of 1 - 8 percent for sizing the desulfurization unit larger for reprocessing off-spec material to meet a number of different sulfur targets. Since meeting a 500 ppm cap standard is not very stringent, Mathpro likely assumed that a desulfurization unit would need to be sized larger by 1 - 4 percent. For meeting the 15 ppm cap standard which is a relatively stringent sulfur standard compared to the 500 ppm sulfur level studied, Mathpro likely assumed the desulfurization unit would be sized larger by 5 - 8 percent. Onsite investment was adjusted to include offsite investment using a factor of 1.4. In the final report, capital costs were amortized at a 15 percent after tax rate of return.

The Mathpro cost study analyzed the costs to comply with the highway program based on 5 different investment scenarios. Before deriving the best nonroad desulfurization cost estimate using the Mathpro cost study, we must describe the various investment scenarios. The titles of the scenarios are listed here:

1. No Retrofitting - Inflexible
2. No Retrofitting - Flexible
3. Retrofitting - De-rate/Parallel
4. Retrofitting - Series
5. Economies of Scale

Scenarios 1 and 2 do not allow retrofitting which means that the existing highway diesel hydrotreater must be removed from service and an new grassroots unit takes its place which desulfurizes untreated distillate down to under 15 ppm. The difference between scenarios 1 and 2 is that scenario 1 does not allow some flexibilities which may be available to the refining industry. One flexibility is that the volume of hydrocracker units is not limited to the used capacity as listed in the 1997 API/NPRA survey, but instead the throughput can be as much as 8 percent higher which is half the available capacity available in the API/NPRA survery. Another flexibility is that jet fuel exceeds specifications and instead of limiting the qualities to current levels, they are instead allowed to become heavier by 0.5 API or by 3 points on the E375 distillation curve and stay within the jet fuel specifications. Allowing jet fuel to get heavier allows the refinery model to bring some of these lighter jet fuel blendstocks into the highway diesel fuel pool which lowers the desulfurization cost. The flexibilities are allowed in the rest of the scenarios as well.

Scenarios 3 and 4 allow taking advantage of the existing highway desulfurization unit by keeping it in place and installing additional capital including additional reactor volume which allows the combined used and new capital to achieve the 15 ppm cap standard. The difference between scenarios 3 and 4 is that Scenario 3 derates the existing hydrotreater which reduces the volume treated by that unit so that it can achieve 15 by itself and then another unit is added in parallel which is also being fed by a low throughput which allows it to meet the 15 ppm cap standard. Scenario 4 installs the new capital in series with the existing hydrotreater with both units handling the entire feed rate.

Scenario 5 allows the debottlenecking of existing capacity to treat a larger volume while producing the same specifications. Scenario 5 also allows a single unit to be installed to handle the desulfurization of multiple refineries in refining centers which provides an important economy of scale for the desulfurization investment costs to that group of refineries.

While these various investment scenarios were devised to understand how different investment scenarios would affect the cost for the highway rule, they have implications for the nonroad rule as well. For meeting a 500 ppm cap nonroad diesel fuel standard, the used highway units which are freed up in Scenarios 1 and 2 can thus be converted over to nonroad service which dramatically reduces the capital cost of compliance, and this supplements the existing nonroad capacity which is already in place. However, for Scenario 2, the installed grassroots capacity installed for the highway rule decreased after the capital was already installed and a larger volume of existing hydrotreating capacity removed from highway desulfurization service was put into place to supplement the nonroad hydrotreating capacity already in place. For Scenario 3, the needed nonroad capacity is formed by adding grassroots capacity. For Scenario 4, the necessary nonroad hydrotreating capacity is formed by increasing the existing unit capacity used, relying on some expansion of existing units and adding some processing unit capacity in series with existing capacity. The nonroad hydrotreating capacity for meeting the 500 ppm cap standard is realized for Scenario 5 similar to Scenario 4, except no expansion of existing units occurs, but instead more capacity from existing highway units is relied upon.

For meeting the 15 ppm cap sulfur standard for nonroad diesel fuel, the refinery model invested in nonroad capital either along the same lines as the 500 ppm case, or else invested much differently. For Scenario 1 and 2, the refinery model installed grassroots units only, even replacing some existing hydrotreating capacity which was likely being used for some mild desulfurization of nonroad diesel fuel. For Scenario 2, the volume of grassroots desulfurization capacity was slightly lower than Scenario 1 probably due to the increased flexibility which the refinery model was granted. For Scenario 3, the refinery model added some new grassroots unit capacity compared to the 500 ppm case, probably derating the capacity of the remaining 500 ppm and new 500 ppm capacity. For Scenario 4, the refinery model added more series unit capacity and more expansion capacity. Finally for Scenario 5, the refinery model increased the series processing unit capacity and added some expansion capacity.

The new or existing hydrotreating capacity used for meeting the 500 ppm and 15 ppm nonroad standards incremental to meeting the highway 15 ppm sulfur standard is shown in Table 7.2-58.

Table 7.2-58
Mathpro Capital Costs for Desulfurizing Highway and Nonroad Diesel Fuel

		No Retr Inflex	No Retr Flex	Retr De-rate	Retr Series	Econ of Scale
Reference Case	Existing Cap	34.9	34.9	34.9	34.9	34.9
Highway 15 ppm Cap Std	Existing Unit	8.2	8.2		31.1	31.1
	Expansion					
	De-rated			17.8		
	Series Unit			15.4	29.4	29.4
	Grassroot Unit	30.2	29.3			
Nonroad Meeting a 500 ppm Cap Standard	Existing Unit	16.5	19.4		35.0	38.0
	Expansion				2.9	
	De-rated			17.8		
	Series Unit				34.1	34.0
	Grassroot Unit	30.1	27.6	23.7		
Nonroad Meeting a 15 ppm Cap Standard	Existing Unit				35.0	38.0
	Expansion				4.9	1.9
	De-rated			17.8		
	Series Unit				39.1	39.1
	Grassroot Unit	50.4	49.3	26.5		

We next needed to determine which of the Mathpro cases which would best approximate the investment scenarios which we are using in our 500 ppm cost analysis. As described above in this section, the refineries which comply with the highway rule in 2006 by putting in a new hydrotreater (20 percent of the mixed highway and nonroad refineries which comply with the highway requirements in 2006 and which have a distillate hydrotreater), thus idling the existing hydrotreater, is projected to use the existing hydrotreater to produce 500 ppm sulfur nonroad diesel fuel in 2007. Those refineries comprise 7 percent of the nonroad pool. The rest of the refineries are expected to install a new unit in 2007 to comply with the 500 ppm sulfur standard. Next, we examined the Mathpro investment cases to match them with the scenarios in our cost analysis. There were no cases which matched our scenario exactly, but we found two Mathpro cases which, together, matched our investment scenario. The first is the No Retrofit Inflexible case which met the nonroad requirements exclusively through using existing capacity. The second case is the retrofitting derating case which met the nonroad requirements through new capital investment. Since our analysis had only 9 percent of the nonroad volume as being produced by refineries which would use the existing hydrotreater to produce 500 ppm sulfur nonroad diesel fuel, the Mathpro costs were weighted 7 percent No Retrofit Inflexible costs and 93 percent and Retrofit DeRate costs.

We then examined the Mathpro 15 ppm cases to determine which of them best matched our 15 ppm scenario. Since we already have identified the Mathpro cases for estimating the incremental cost for going from meeting the 500 ppm standard to meeting the 15 ppm sulfur standard, we needed to consider how to adjust the costs to remove any costs associated with going from untreated to 500 ppm. As discussed above in this section, our 15 ppm scenario has new nonroad diesel fuel hydrotreating units being installed in 2010, although those which are mixed highway and nonroad refineries are expected to install their highway and nonroad units together taking advantage of the economies of scale for doing so. Of the Mathpro cases summarized above, the first two cases, which don't allow revamps and either allow or don't allow operational flexibility, install grassroots units for obtaining the 15 ppm standard. Since the second Mathpro case apparently allowed backsliding in the highway grassroots units needed for complying with the highway rule when the 500 ppm standard was being met which we don't think is possible because the highway investments will be too far along before the nonroad program is finalized, we decided to use Mathpro's case one.

Case one, however, needed to be adjusted to develop a scenario which we believe is more realistic based on how refiners are likely to comply with the highway and nonroad programs. Mathpro's case one was associated with the replacement of the existing hydrotreating capacity which was likely used for desulfurizing nonroad down to 500 ppm. However, we believe that 80 percent of the existing nonroad desulfurization capacity can be revamped instead of having to be replaced. Thus, we adjusted the Mathpro capital costs to remove the extra grassroots hydrotreating capacity. We accomplished this by estimating what percent of the capital costs is necessary for complying with 15 ppm standard and for replacing the expected portion of existing nonroad desulfurization capital. The nonroad diesel fuel volume needed to be treated in Mathpro's notional refinery model is 9 thousand barrels per day. According to Mathpro, the capital needed to be installed to treat the nonroad pool down to 15 ppm is increased by 10 percent to handle peak throughput rates, and then by another 10 percent to handle peak seasonal rates and then by another 8 percent to handle reprocessing of off-spec batches. Thus the 9,000 barrels per day nonroad volume is increased to about 11,800 barrels per day which represents Mathpro's estimated capital capacity. We subtracted 11,800 bpd from the total volume of grassroots capacity added, which was 20,300 bpd, to yield a total of 8,500 barrels per day of replaced capital capacity which we assumed would be untreated to 500 ppm nonroad hydrotreated capacity. Since we believe that it is reasonable that 20 percent of this existing capacity would be replaced, we maintained 20 percent of 8,500 bpd, or an additional 1,700 barrels of the new nonroad hydrotreating capacity. Therefore, we maintained 13,500 bpd of the original 20,300 bpd of additional capacity added in Mathpro case one. To estimate a revised cost for Mathpro's case one we multiplied the capital charge by a ratio of 13,500/20,300. No adjustment was necessary for the variable operating cost.

In addition to the differences and adjustments as described above, there are several other differences between our cost analysis and the cost analysis made by Mathpro which deserve mentioning or which were adjusted. First, the MathPro costs as reported in their final report are based on a 15 percent return on investment (ROI) after taxes. As stated above, our costs are calculated based on a 7 percent ROI before taxes, so to compare our cost analysis with the cost analysis made by Mathpro, we adjusted the Mathpro costs to reflect the rate of return on capital investment which we use. Second, the MathPro estimate includes a cost add-on (called an ancillary cost) for reblending and reprocessing offspec diesel fuel or for storing nontreated diesel fuel. While this is conceptually an appropriate adjustment, it appears that some of the reblending costs in the MathPro study appear to be transfer payments,[m] not costs. Third, MathPro assumed that all new hydrogen demand is met with new hydrogen plants installed in the refinery, which does not consider the advantage of hydrogen purchased from a third party which can be produced cheaper in many cases. As a result, their hydrogen cost may be exaggerated, which would tend to increase costs. Finally, it should be noted that the MathPro study did take into consideration the need for lubricity additives, but did not address costs that might be incurred in the distribution system. Thus, in a comparison of our costs with Mathpro's, we will include our cost estimate for adding the appropriate amount of lubricity additive, but not add on the distribution costs. For comparing the aggregate capital costs, the Mathpro aggregate capital costs for the cases which were chosen were adjusted using the undesulfurized nonroad, locomotive and marine diesel fuel volumes for 2007 and for undesulfurized nonroad diesel fuel for 2010. The undesulfurized volumes which we used for making the adjustments are presented in Section 7.1 of the draft RIA. A comparison of Mathpro's costs and our costs to desulfurize highway diesel fuel to meet a 500 ppm sulfur cap standard and then a 15 ppm sulfur cap standard is shown below in Table 7.2-59.

Table 7.2-59
Comparison of Mathpro's and EPA's
Refining Costs for Meeting a 500 ppm and a 15 ppm Nonroad Diesel Fuel Sulfur Cap Standard (7% ROI before taxes, no lubricity additive costs nor distribution costs included)

Fuel Standard	Type of Cost	Mathpro's Costs	EPA's Costs	
		No Advanced Tech	Advanced Tech in 2010	No Advanced Tech
500 ppm Cap Std.	Per-gallon Cost (c/gal)	2.5	2.2	2.2
	Total Capital Cost (billion$)	925	612	612
15 ppm Cap Std. Incremental to 500 ppm Std.	Per-gallon Cost (c/gal)	3.3	2.2	3.3
	Total Capital Cost (billion$)	836	649	606
Uncontrolled to 15 ppm	Per-gallon Cost (c/gal)	5.8	4.4	5.5
	Total Capital Cost (billion$)	1761	1261	1218

[M] A transfer payment is when money changes hands, but no real resources (labor, natural resources, manufacturing etc.) are consumed.

7.3 Cost of Distributing Non-Highway Diesel Fuel

7.3.1 Distribution Costs Under the 500 ppm Sulfur Non-Highway Diesel Fuel Program

7.3.1.1 Fuel Distribution-Related Capital Costs Under the 500 ppm Sulfur Non-Highway Diesel Fuel Program

The potential capital costs associated with distributing 500 ppm sulfur non-highway diesel fuel pertain to the need for additional product segregation which might result. Section 5.4.2 of this draft RIA evaluates the potential for additional product segregation in each segment of the distribution system. The projected capital costs associated with distribution non-highway diesel fuel meeting the proposed 500 ppm standard are limited to the need for approximately 1,000 bulk plants to add an additional storage tank and demanifold their delivery truck to handle an additional diesel product.

In its comments to the government/industry panel convened in accordance with the Small business Regulatory enforcement Act (SBRFA), the Petroleum Marketers Association of America (PMAA) stated that depending on the location, the cost of installing a new diesel storage tank at a bulk plant would range from $70,000 to $100,000. To provide a conservatively high estimate of the cost to bulk plant operators, we used an average cost of $90,000. This is consistent with the information we obtained from a contractor working for EPA (ICF Kaiser) on the installed cost of a 20,000 gallon diesel storage tank which is the typical tank size at bulk plant facilities. Demanifolding of the bulk plant operators delivery truck involves installing an internal bulkhead to make two tank compartments from a single compartment. To help control contamination concerns, we also estimated that an additional fuel delivery system would be installed on the tank truck(i.e. so that there would be a separate delivery system for each fuel carried by the delivery truck). The cost of demanifolding a tank truck and installing a an additional fuel delivery system is estimated at $10,000, of which $6,000 is the cost of installing a new fuel delivery system.[49] Thus, the cost to each of the affected bulk plants would be $100,000 for a total cost of $100,000,000.

Amortizing the capital costs over 20 years, results in a estimated cost for tankage at such bulk plants of 0.1 cent per gallon of affected non-highway diesel engine fuel supplied. Twenty years was chosen due to the very long life of fuel storage tanks, and their lack of obsolescence. Although the impact on the overall cost of the proposed program is small, the cost to those bulk plant operators who need to put in a separate storage tank may represent a substantial investment. Thus, we believe many of these bulk plants could make other arrangements to continue servicing both heating oil and NRLM markets. In some cases, two or more bulk plants within a given service area may a have a single owner. In these cases, the bulk plant operator could continue to serve both markets by storing heating oil at one facility and nonroad fuel at the other. However, it would be more likely that multiple bulk plants serving a given geographic area would have different owners. In such cases, exchange agreements could be worked out between the two bulk plant operators so that they could continue to serve both markets.

7.3.1.2 Distribution Costs Due to the Reduction in Fuel Volumetric Energy Content Under the Proposed 500 ppm Sulfur Diesel Fuel Program

We estimate that desulfurization of non-highway diesel fuel to meet the proposed 500 ppm sulfur standard would result in a 0.7 percent reduction in the volumetric energy content (VEC) of the affected fuel (see section 5.9.2 of this draft RIA). This increases the cost to distribute diesel fuel due to the increased volume.

We believe that the difference between the price of non-highway diesel fuel to end-users and the price to resellers provides an appropriate estimate of the cost of distributing non-highway diesel fuel. The Energy Information Administration (EIA) publishes data regarding the price excluding taxes of high-sulfur #2 diesel fuel to end-users versus the price to resellers. We used the five year average of the difference between these two prices to arrive at an estimated typical cost of distributing non-highway diesel fuel to the end-user of 10 cents per gallon. The following table (7.3-1) presents the EIA data that we used in estimating the cost of distributing non-highway diesel fuel.

Table 7.3-1
Cost of Distributing High-Sulfur #2 Diesel Fuel[a]
(cents per gallon, excluding taxes)

Year	Sales to End Users	Sales to Resellers	Difference Between Sales to End Users & Sales to Resellers
1995	52.4	61.4	9.0
1996	63.9	73.2	9.3
1997	60.2	69.8	9.6
1998	43.7	55.5	11.8
1999	51.9	62.0	10.1
5 Year Average	54.4	64.4	10.0

[a] Energy Information Administration, Annual Energy Review 2001

We assumed that the current 10 cent per gallon cost of distributing diesel fuel would stay constant. For example, a one percent increase in the amount of fuel distributed would increase total distribution costs by one percent. Thus, the 0.7 percent reduction in VEC is estimated to result in a 0.07 cents per gallon increase in the cost to distribute non-highway diesel fuel. This cost was applied to the gallons of non-highway diesel fuel that would need to be desulfurized to meet the proposed 500 ppm sulfur standard. This cost was applied to NRLM from June 2007 through June 2010 when the proposed 15 ppm sulfur standard for nonroad diesel fuel would be implemented. After June 2010, this cost applies to LM fuel only. The additional costs associated with the further reduction in nonroad diesel fuel VEC associated with desulfurization to meet a 15 ppm sulfur specification are discussed in section 7.3.2.2 of this draft RIA.

Since the difference in price at the refiner rack versus that at retail also includes some profit for the distributor and retailer, its use provides a conservatively high estimate of distribution costs. The fact that a slightly less dense (lighter, less viscous) fuel would require slightly less energy to be distributed also indicates that this estimate is conservative.

7.3.1.3 Other Potential Distribution Costs Under the Proposed 500 ppm Sulfur Diesel Fuel Program

We anticipate that there would be no other significant distribution costs associated with the adoption of the proposed 500 ppm non-highway diesel sulfur standard beyond those described in sections 7.3.1.1 & 2 above. As discussed in section 5.4 of this draft RIA, we do not expect the need for additional storage tanks beyond that discussed in section 7.3.1.2 above, an increase in pipeline downgrade or transmix volumes, or the need for additional facilities at the refinery to comply with the proposed fuel marker requirements.

Bulk plant and tank truck who previously only handled high-sulfur diesel fuel would need to begin observing practices to limit sulfur contamination during the distribution of 500 ppm diesel fuel. However, these practices are well established and are primarily associated with purging storage tanks and fuel delivery systems of high-sulfur diesel fuel prior to the use in handling 500 ppm diesel fuel. Such tasks can be readily accomplished. Training of employees would be necessary to impress the importance of consistently and carefully observing the practices to limit sulfur contamination. However, we estimate the costs associated would be minimal. In addition, we are estimating that most of the affected bulk plant operators would install dedicated storage tanks and truck delivery systems. This would obviate the need for much of the cautionary actions necessary to limit sulfur contamination when both low and high sulfur diesel fuel is carried by the same marketer.

7.3.2 Distribution Costs Under the 15 ppm Sulfur Nonroad Diesel Fuel Program

7.3.2.1 Fuel Distribution-Related Capital Costs Under the 15 ppm Sulfur Nonroad Diesel Fuel Program

As discussed in section 5.6 of this draft RIA, we do not anticipate that the implementation of the proposed 15 ppm sulfur standard would result in the need for fuel distribution industry to make changes that would require investment capital. Specifically, we project that there would be no substantial need for additional storage tanks or other facility changes to ensure product segregation.

7.3.2.2 Distribution Costs Due to the Reduction in Fuel Volumetric Energy Content Under the 15 ppm Sulfur Nonroad Diesel Fuel Program

We project that desulfurizing diesel fuel to 15 ppm would reduce volumetric energy content of the affected fuel by an additional 0.35 percent in addition the 0.7 percent reduction in VEC which accompanied desulfurization to meet the proposed 500 ppm standard. Thus, the total reduction in the VEC of nonroad diesel fuel which would need to be desulfurized to meet the proposed 15 ppm standard would be 1.1 percent (see section 5.9.2).

The methodology described in 7.3.1.2. for the calculation of the increase in distribution costs due to the reduction in VEC associated with meeting the proposed 500 ppm sulfur standard is also applicable in calculating the increase in distribution costs associated with meeting the proposed 15 ppm nonroad standard. Using this methodology, we estimate that the additional 0.35 percent reduction in the VEC of nonroad diesel fuel would increase the cost of distributing the affected gallons of 15 ppm nonroad diesel fuel by an additional 0.04 cent per gallon. Thus, the total increase in distribution costs associated with the decrease in VEC of 15 ppm nonroad diesel fuel would be 0.11 cent per gallon of affected nonroad diesel pool. This cost was applied to the volume of nonroad diesel fuel that would need to be desulfurized to meet the proposed 15 ppm standard beginning in June 2010.

7.3.2.3 Other Potential Distribution Costs Under the 15 ppm Sulfur Nonroad Diesel Fuel Program

We anticipate that there would be no other significant distribution costs associated with the adoption of the proposed 500 ppm non-highway diesel sulfur standard beyond those described in sections 7.3.1.1 & 2 above. As discussed in section 5.4 of this draft RIA, we do not expect the need for additional storage tanks beyond that discussed in section 7.3.1.2 above, an increase in pipeline downgrade or transmix volumes, or the need for additional facilities at the refinery to comply with the proposed fuel marker requirements.

Bulk plant operators who previously only handled high-sulfur heating oil would need to begin observing practices to limit sulfur contamination during the distribution of 1 ppm diesel fuel. However, these practices will be established well in advance as entities comply with the 15 ppm highway standard in 2006. These practices include purging storage tanks and fuel delivery systems of high-sulfur diesel fuel prior to the use of the equipment in handling 1500 ppm diesel fuel.. Training of employees would be necessary to impress the importance of consistently and carefully observing the practices to limit sulfur contamination. However, we estimate the costs associated would be minimal. In addition, we are estimating that most of the subject bulk plant operators would install dedicated storage tanks and truck delivery systems. This would obviate the need for much of the cautionary actions necessary to limit sulfur contamination when both low and high sulfur diesel fuel is carried by the same marketer.

As discussed in section 4.6 in this draft RIA, the vast majority of the fuel distribution system (primarily pipeline and terminal facilities) will already have optimized their facilities and procedures to limit sulfur contamination during the distribution of 15 ppm diesel fuel sulfur contamination due to the need to comply with the highway diesel fuel program in 2006. The costs associated with this optimization process were accounted for in the highway diesel program's RIA.[50] Highway diesel fuel and nonroad diesel fuel meeting a 15 ppm sulfur specification would share the same distribution system until nonroad diesel fuel would be dyed as it leaves the terminal to meet IRS requirements. Therefore, we do not expect there would be any additional actions and associated costs needed to optimize the distribution system to limit sulfur contamination during the distribution of 15 ppm nonroad diesel fuel.

A small fraction of bulk plant and tank truck operators who do not handle highway diesel may have had no prior experience in limiting sulfur contamination during the distribution of 15 ppm diesel fuel prior to the implementation of the proposed 15 ppm nonroad diesel sulfur standard in 2010. These would be the same entities that may have had no prior experience in distributing 500 ppm diesel fuel prior to the implementation of the 500 ppm NRLM sulfur standard in 2008. Consistent with the projections developed in the final highway diesel fuel rule regarding the handling practices for 15 ppm diesel fuel we believe that such entities would only need to more carefully and consistently observe standard industry practices regarding purging tanks and delivery lines of higher-sulfur product prior to the use in delivering 15 ppm nonroad diesel fuel.[51] Additional training may be needed of there operators to emphasize the criticality following such procedures. However, we believe that such training and the associated costs would be minimal.

7.3.3 Cost of Lubricity Additives

Our evaluation of the potential impact of the proposed non-highway diesel sulfur standards on fuel lubricity is contained in section 5.9 of this draft RIA. We concluded that the increased need for lubricity additives that would result from the adoption of these proposed sulfur standards would be similar to that for highway diesel fuel meeting the same sulfur standard.

The highway diesel final rule estimated that all diesel fuel meeting a 15 ppm sulfur standard would require the use of lubricity additives at a cost would be 0.2 cents per gallon.[52] As noted above, we concluded that the impact on fuel lubricity of meeting a 15 ppm sulfur standard for non-highway diesel fuel would be similar to that experienced in meeting15 ppm highway diesel sulfur standard. Therefore, consistent with the estimated cost due the increased use of lubricity additives in 15 ppm highway diesel fuel, we have included a charge of 0.2 cents per gallon in our cost calculation associated with today’s action to account for cost for the increased use of lubricity additives in 15 ppm nonroad diesel fuel. This lubricity additive cost would be applicable to the affected nonroad diesel fuel pool beginning in 2010.

In estimating lubricity additive costs for 500 ppm diesel fuel we assumed that the same additive concentration needed in 15 ppm diesel fuel would also be needed in 500 ppm diesel fuel that needs such an additive, and that 5 percent of all 500 ppm diesel fuel would require a lubricity additive. Based on these assumptions, we estimate that the cost of additional lubricity additives for the affected 500 ppm NRLM diesel fuel would be 0.01 cents per gallon. The amount of lubricity additive needed increases substantially as diesel fuel is desulfurized to lower levels. Also, based on the industry input (see section 5.9 of this Draft RIA) it is likely that substantially less that 5 percent of 500 ppm diesel fuel outside of California requires a lubricity additive. Therefore, we believe that 0.01 cent per gallon represents a conservatively high estimate of the cost of lubricity additives for affected volume of 500 ppm nonroad, locomotive and marine diesel fuel. Although, the actual cost would likely be considerably less, we have no information with which to better quantify the percentage of 500 ppm diesel fuel that is currently treated with a lubricity additive or the appropriate additive treatment rate. Hence, it seems most appropriate to use an estimate that is conservatively high. The 0.01 cents per gallon lubricity additive cost would be applicable to the affected non-highway diesel pool (NRLM) until the proposed reduction in the sulfur standard for nonroad diesel fuel to 15 ppm would be implemented in 2010. After 2010, the 0.01 cents per gallon lubricity additive cost would be applicable to the affected locomotive and marine pool.

7.3.4 Fuel Marker Costs

Under the proposed requirement, high sulfur heating oil would be marked between 2007 and 2010 and locomotive and marine diesel fuel would be marked from 2010 until 2014. After 2014 the proposed marker requirement would expire.

Our conversations with marker manufactures indicate that the cost to treat fuel with either of the markers considered in the proposed rule would be lower than the costs to treat non-highway diesel fuel with red dye to meet IRS requirements. A major pipeline charges 0.2 cents per gallon to inject red dye to IRS specifications. We believe that this represents a conservatively high estimate of treatment costs for the markers under consideration. For the purposes of our cost calculations, we applied the annual cost of treating heating oil volumes with marker to the affected NRLM pool from June 2007 through June 2010. This results in a charge for the heating oil marker used during this time period of 0.16 cents per gallon of affected NRLM fuel. For the time period from June 2010 though June 2014 the cost of marking locomotive and marine diesel fuel was applied to the locomotive and marine pool itself. Thus, the marker costs during this time period are estimated at 0.2 cents per gallon of affected locomotive and marine diesel fuel. Please refer to section 7.1 of this draft RIA regarding the volume of 15 ppm diesel fuel we estimate would be used in locomotive and marine diesel fuel.

7.3.5 Distribution, Lubricity, and Marker Costs Under Alternative Sulfur Control Options

Distribution costs vary from 0.2 to 0.4 cents per gallon of affected diesel fuel under the alternative options considered. The variation in distribution cost is relatively insignificant compared to the variation in refining costs (see section 7.2 of this draft RIA).

Distribution costs vary due to differences in the volumetric energy density (VEC), marker and lubricity additive cost components. Under all of the alternative options considered the cost of additional storage tanks remains constant (0.1 cents per gallon).

Since the reduction in VEC is a side-effect of the desulfurization process, the increase in distribution costs associated it varies directly with the timing and applicability of the sulfur standards for NRLM. The earlier NRLM would be desulfurized, the earlier the charge for VEC must be applied. Since the reduction in VEC is higher in meeting a 15 ppm standard (0.07 cents per gallon) versus a 500 ppm standard (0.11 cents per gallon), costs related to reduced VEC increases if the 15 ppm sulfur standard would be more broadly applicable and/or the implementation of the standard would be earlier.

There is relatively little lubricity additive cost associated with desulfurization to meet a 500 ppm standard (0.01 cents per gallon) compared to that associated with desulfurization to meet a 15 ppm standard (0.2 cents per gallon). Consequently, distribution costs related to the need for additional lubricity additive increases if the 15 ppm sulfur standard would be more broadly applicable and/or the implementation of the standard would be earlier.

Marker related costs also vary based on the timing and applicability of the sulfur standards under consideration. Under some alternative options, marker costs apply for a longer or shorter duration and/or to a larger or smaller diesel pool.

A summary of the distribution costs under the various alternative options is presented in following table 7.3-2. A more complete discussion of the alternative options considered can be found in chapter 12 of this draft RIA. Please refer to section 7.1. regarding the volumes of fuel that these costs apply to. The net fuel related costs under the various sulfur control options under consideration is contained in section 7.5 of this draft RIA.

Table 7.3-2
Distribution and Additive Costs under Non-Highway Diesel Control Options (c/gal)[a]

Control Option	Sulfur Specifications	Year	Reduction in VEC	Additional Storage Tanks[b]	Additional Lubricity Additive	Marker[c]	Total Distribution & Additive Costs
Proposal	500 ppm NR, L & M	2007 - 2010	0.07	0.1	0.01	0.16	0.3
	500 ppm L & M	2010 - 2014	0.07	0.1	0.01	0.2	0.4
	15 ppm NR	2010 +	0.11	0.1	0.2	NA	0.4
	500 ppm L & M	2014 +	0.07	0.1	0.01	NA	0.2
Proposal with 15 ppm NR in 2009	500 ppm NR, L & M	2007 - 2009	0.07	0.1	0.01	0.16	0.3
	500 ppm L & M	2009 - 2013	0.07	0.1	0.01	0.2	0.4
	15 ppm NR (total incl 2007)	2009 +	0.11	0.1	0.2	NA	0.4
	500 ppm L & M	2013 +	0.07	0.1	0.01	NA	0.2
Proposal with NR, L & M to 15 ppm in 2010	500 ppm NR, L & M	2007 - 2010	0.07	0.1	0.01	0.16	0.3
	15 ppm NR, L & M (total incl 2007)	2010 +	0.11	0.1	0.2	NA	0.4

[a] Legend: NR= Nonroad diesel, L = Locomotive diesel, M = Marine diesel, VEC = Volumetric energy content

[b] Costs applied to “affected” gallons, i.e., gallons of fuel destined for a given end-use that would be desulfurized under given control option.

[c] When marker would be required in heating oil, costs are applied to affected NR, L, & M volume. When marker would be required in L &M, costs are applied to affected L, & M volume.

7.4 Net Cost of the Two-Step Nonroad Diesel Fuel Program

The estimated refining costs from Subsection 7.2.2 and distribution and additive costs from Sections 7.3 and 7.4 for the Proposed Nonroad Program and the other fuel options considered are summarized together in the following table. Both the 2007 and the 2010 costs are presented in the table. Note that these fuel costs do not include the impacts of the small refiner exemptions.

Table 7.4-1
Table of Fuel Costs for Nonroad Program Control Options (cents per gallon and $2002)

Option	Specification	Year	Refining Costs (c/gal)	Distribution & Additive Costs (c/gal)	Total Costs (c/gal)
Proposal - Locomotive and Marine to 500 ppm and NR to 15 ppm	500 ppm NR, L & M	2007	2.2	0.3	2.5
	500 ppm L & M	2010	2.2	0.4	2.6
	15 ppm NR (total incl 2007)	2010+	4.4	0.4	4.8
	500 ppm L & M	2014+	2.2	0.2	2.4
One Step Locomotive & Marine to 500 ppm and NR to 15 ppm	500 ppm L & M	2008	2.2	0.4	2.5
	15 ppm NR	2008+	4.8	0.4	5.2
	500 ppm L & M	2012+	2.2	0.2	2.4
Nonroad goes to 15 ppm in 2009	500 ppm NR, L & M	2007	2.2	0.3	2.5
	500 ppm L & M	2009	2.2	0.4	2.5
	15 ppm NR (total incl 2007)	2009+	4.6	0.4	5.0
	500 ppm L & M	2013+	2.2	0.2	2.4
Nonroad, Locomotive and Marine go to 15 ppm	500 ppm NR, L & M	2007+	2.2	0.3	2.5
	15 ppm NR, L & M (total incl 2007)	2010+	4.6	0.4	5.0

Our projected total cost for producing 500 ppm fuel is essentially identical to the historical price differential between 500 ppm highway diesel and uncontrolled high sulfur diesel. This differential has averaged about 2.5 cents per gallon for the five year period from 1995 to 1999. Arguably, this differential would minimally account for refiners costs to hydrotreat and distribute a 500 ppm diesel fuel. While cost and prices are not always directly related, the fact that the two numbers are so closely aligned provides added assurance that our cost estimates are reasonable.

7.5 Potential Fuel Price Impacts

Transportation fuel prices are dependent on a wide range of factors, such as world crude oil prices, economic activity at the national level, seasonal demand fluctuations, refinery capacity utilization levels, processing costs, including fuel quality specifications, the cost of alternative energy sources (e.g., coal, natural gas), etc. Most of these factors would be unaffected by the proposed NRLM diesel fuel standards. However, a few, namely fuel processing costs and refinery capacity utilization could or would be affected by the proposed NRLM fuel program.

Fuel processing and distribution costs would clearly be affected due to the cost of desulfurizing NRLM diesel fuel to either the 500 or 15 ppm sulfur cap. Refinery utilization levels could be affected as the capacity to produce 500 ppm or 15 ppm NRLM diesel fuel would depend on refiners' investment in desulfurization capacity. The potential impact of increased fuel processing and distribution costs on the prices will be assessed below. The impact of the proposed rule on refinery utilization levels is beyond the scope of this analysis. In the long run, refiners would clearly invest to produce adequate volumes of NRLM diesel fuels, as well as other distillate fuels. In the shorter term, the issue of refiners' adequate investment in desulfurization capacity was already addressed in Chapter 5.9 above.

Two approaches to projecting future price impacts are evaluated here. The most direct approach to estimating the impact of the proposed NRLM fuel program on prices is to observe the price premiums commanded by similar products in the marketplace. This is feasible for 500 ppm NRLM diesel fuel, as both 500 ppm highway diesel fuel and high sulfur diesel fuel are both marketed today. As discussed in Section 7.2.2 above, the historical price premium of 500 ppm highway diesel fuel is 2.5 cents per gallon over that of high sulfur distillate. As this premium is essentially the same as our projected average total cost of the supplying 500 ppm NRLM diesel fuel, it represents one reasonable estimate of the future price impact of the 500 ppm NRLM diesel fuel standard.

It is not possible to use this methodology to project the price impact of the 15 ppm nonroad diesel fuel cap. Only a very limited amount of diesel fuel meeting a 15 ppm sulfur cap is marketed today in the U.S. This fuel is designed to be used in vehicle fleets which have been retrofitted with particulate traps. The fuel is produced in very limited quantities using equipment designed to meet the current EPA and California highway diesel fuel standards. It is also much more costly to distribute due to its extremely low volume. Thus, the current market prices for 15 ppm diesel fuel in the U.S. are not at all representative of what might be expected in 2010 under the proposed standard.

A greater volume, though still not large quantities, of 10 ppm sulfur diesel fuel is currently being sold in Europe. The great majority of this fuel is Swedish Class 1 (so-called City) diesel fuel, which is essentially a number one diesel fuel with very low aromatic content. The low aromatic specification significantly affects the cost of producing this fuel. Also, this fuel is generally produced using equipment not originally designed to produce 10-15 ppm sulfur fuel. Thus, as in the U.S., the prices paid for this fuel are not representative of what would occur in the U.S. in 2010. Therefore, we did not attempt to use fuels sold today which have sulfur levels similar to the standards we are proposing to evaluate our cost estimate for complying with the 15 ppm cap standard.

The other approach to project potential price impacts utilizes the projected costs to meet the 500 ppm and 15 ppm NRLM fuel sulfur caps. Both sulfur caps would affect fuel processing and distribution costs across the nation. (The exception would be California, where we presume that sulfur caps at least as stringent as those being proposed federally will already be in effect.) However, these costs appear to vary significantly from region to region. Because of the cost of fuel distribution and limited pipeline capacities (pipelines are the most efficient means of transporting fuel), the NRLM fuel markets, and those for other transportation fuels are actually regional in nature. Price differences can and usually do exist between the various regions of the country. Because of this, we have performed our assessment of potential price impacts on a regional basis. For the regions in our analysis, we have chosen PADDs. Practically speaking, there are probably more than five fuel markets in the U.S. with distinct prices. However, analyzing five distinct refining regions appears to provide a reasonable range of price impacts without adding precision that significantly exceeds our ability to project costs.

We made one exception to the PADD structure. PADD 3 (the Gulf Coast) supplies more high sulfur distillate to PADD 1, particularly the Northeast, than is produced by PADD 1 refineries. Two large pipelines connect PADD 3 refineries to the Northeast, the Colonial and the Plantation. Because of this low cost transportation connection, prices between the two PADDs are closely linked. We therefore combined our price analysis for PADDs 1 and 3.

As mentioned above, it is very difficult to predict fuel prices, either in the short term or long term. Over the past three years, transportation fuel prices (before excise taxes) have varied by a factor of two. Therefore, we have avoided any attempt to project absolute fuel prices. Because of the wide swings in absolute fuel prices, it is very difficult to assess the impact of individual factors on fuel price. The one exception is the price of crude oil, for two reasons. One, the cost of crude oil is the dominant factor in the overall cost of producing transportation fuels. Two, the pricing of essentially all crude oils is tied to the “world” market price of crude oil. While the cost of producing crude oil in each region of the world is independent of those of other crude oil, contract prices are tied to crude oils which are traded on the open market, such as West Texas Intermediate and North Sea Brent crude oils. Thus, as the price of world crude oil climbs, the price of gasoline and diesel fuel climb across the U.S., and vice versa. There is also a very rough correlation between refinery capacity utilization levels and fuel price. However, an unusually high availability of imports can cause prices to be relatively low despite high refinery capacity utilization rates in the U.S.

For example, fuel prices, as a function of crude oil price, have varied widely over the past decade. Refiner records supplied to EIA indicate that refiners' net refining margin has ranged from a low of $0.49 per barrel in 1992 to a high of 2.23 per barrel in 2000.[n] Thus, fuel prices have varied between being so low that refineries are barely covering their cash expenses to high enough to justify moderate cost increases in refining capacity (but not new refineries). The proposed NRLM rule would be very unlikely to have a major impact on factors such as these. Thus, projecting the likely price impact of the proposed rule is highly speculative. The best that can be done is to develop a wide range of potential price impacts indicative of the types of conditions which have existed in the past.

To do this, we developed three projections for the potential impact of the proposed fuel program on fuel prices. The lower end of the range assumes a very competitive NRLM fuel market with excess refining capacity. In this case, fuel prices within a PADD are generally low and only reflect incremental operating costs. Consistent with this, under this assumption, we project that the price of NRLM diesel fuel within a PADD would increase by the operating cost of the refinery with the highest operating cost in that PADD. This assumes that the refinery facing the highest operating cost in producing NRLM diesel fuel is setting the price of NRLM diesel fuel prior to this rule. This may or may not be the case. If not, the price increase could be even lower than that projected below. Under this "low cost" set of assumptions, the refiner with the highest operating cost would not recover any of his invested capital related to desulfurizing NRLM diesel fuel, but all other refiners would recover some of their investment.[o]

The mid-range estimate of price impacts could be termed the "full cost" scenario. It assumes that prices within a PADD increase by the average refining and distribution cost within that PADD, including full recovery of capital (at the societal rate of return of 7% per annum before taxes). Unlike the low and high price scenarios, the mid-range, full cost price scenario does not have a direct connection with economic pricing theory. It simply represents a convenient price estimate which falls between the low and high price estimates.

Under this full cost price scenario, lower cost refiners would recover their capital investment plus economic profit, while those with higher than average costs would recover some of their invested capital, but not all of it (i.e., at a lower rate of return than 7% per annum).

The high end estimate of price impacts assumes a NRLM fuel market that is constrained with respect to fuel production capacity. Prices rise to the point necessary to encourage additional desulfurization capacity. Also, prices are assumed to remain at this level in the long term, meaning that any additional desulfurization capacity brought on barely fulfills demand and does

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[N] Inflation adjusted dollars. EIA, Form EIA-28, Financial Reporting System, updated June 27, 2002.

[O] Theoretically, some refiners might recover all of their invested capital if their operating costs were sufficiently lower than those of the high cost refiner. However, practically, in the case of desulfurizing NRLM diesel fuel, this is highly unlikely.

not create an excess in capacity which would tend to reduce prices. However, prices should not increase beyond this level in the long run, as this would encourage the construction of additional desulfurization capacity, lowering prices. Consistent with this, prices within a PADD increase by the maximum total refining and distribution cost of any refinery within that PADD, including full recovery of capital (at 7% per annum before taxes). All other refiners would recover more than their capital investment.

The range of potential price increases resulting from these three sets of assumptions are shown in Table 7.5-1. The wholesale price of high sulfur distillate fuel has varied widely even over the past 12 months. The March 2003 heating oil futures price alone has ranged from 60-110 cents per gallon since early 2002. Assuming a base cost of NRLM fuel of one dollar per gallon, the increase in NRLM fuel prices would be equivalent to the price increase in terms of cents per gallon shown below.

Table 7.5-1
Range of Possible Total Diesel Fuel Price Increases (cents per gallon)[a]

	Low Price	Mid-Point	High Price
2007 500 ppm Sulfur Cap: Nonroad, Locomotive and Marine Diesel Fuel			
PADDs 1 and 3	0.9	1.5	3.4
PADD 2	2.3	3.0	4.8
PADD 4	1.7	4.1	5.8
PADD 5	1.0	2.8	4.3
2010 15 ppm Sulfur Cap: Nonroad Diesel Fuel			
PADDs 1 and 3	1.8	3.0	5.4
PADD 2	2.9	6.1	7.4
PADD 4	3.0	8.9	9.3
PADD 5	1.7	5.9	8.4

[a] At a wholesale price of approximately $1.00 per gallon, these values also represent the percentage increase in diesel fuel price.

Under the low price scenario, the price of nonroad, locomotive and marine diesel fuel would increase in 2007 by 1-2 cents per gallon, depending on the area of the country. In 2010, the price of nonroad diesel fuel would increase a total of 2-3 cents per gallon. Locomotive and marine diesel fuel prices would continue to increase by 1-2 cents per gallon.

Under the mid-point price scenario, the price of nonroad, locomotive and marine diesel fuel would increase in 2007 by 2-4 cents per gallon, depending on the area of the country. In 2010, the price of nonroad diesel fuel would increase a total of 3-9 cents per gallon. Locomotive and marine diesel fuel prices would continue to increase by 2-4 cents per gallon.

Under the high price scenario, the price of nonroad, locomotive and marine diesel fuel would increase in 2007 by 3-6 cents per gallon, depending on the area of the country. In 2010, the price of nonroad diesel fuel would increase a total of 5-9 cents per gallon. Locomotive and marine diesel fuel prices would continue to increase by 3-6 cents per gallon.

Appendix 7A: Estimated Total Off-Highway Diesel Fuel Demand and Diesel Sulfur Levels

Table 7A-1 was used to derive Table 7.1-3.

Table 7A-1
Estimated Total Non-Highway Diesel Fuel Demand[a]

Category	Area	No. 1	L.S. Diesel	Diesel	No. 2 F.O.	Distillate F.O.	Total Distillate	Other Distillate	H.S. Diesel	Total*
Total	US	0.236	1.871	3.260	8.019	8.961	0.000	0.143	1.363	23.853
	California	0.001	0.122	0.261	0.010	0.520	0.000	0.000	0.007	0.921
	Alaska	0.043	0.004	0.006	0.041	0.160	0.000	0.000	0.000	0.254
	Hawaii	0.000	0.004	0.019	0.000	0.106	0.000	0.000	0.000	0.129
	49 State	0.235	1.749	2.999	8.009	8.441	0.000	0.143	1.248	22.824
	PADD I	0.012	0.534	0.430	6.914	1.984	0.000	0.073	0.500	10.447
	PADD II	0.134	0.452	1.587	0.770	2.318	0.000	0.061	0.438	5.760
	PADD III	0.004	0.339	0.558	0.147	2.992	0.000	0.003	0.276	4.319
	PADD IV	0.033	0.271	0.221	0.045	0.563	0.000	0.004	0.034	1.171
	PADD V	0.053	0.274	0.462	0.144	1.103	0.000	0.002	0.115	2.153
Residential	US	0.118			6.086					6.204
	California	0.000			0.007					0.007
	Alaska	0.023			0.025					0.048
	Hawaii				0.000					0.000
	49 State	0.118	0.000	0.000	6.079	0.000	0.000	0.000	0.000	6.197
	PADD I	0.008			5.391					5.399
	PADD II	0.072			0.557					0.629
	PADD III	0.000			0.001					0.001
	PADD IV	0.009			0.030					0.039
	PADD V	0.029			0.108					0.137
Commercial	US	0.064	1.061		1.576				0.474	3.175
	California	0.000	0.079		0.003				0.005	0.087
	Alaska	0.01	0.004		0.012					0.026
	Hawaii		0.003		0.000					0.003
	49 State	0.064	0.982	0.000	1.573	0.000	0.000	0.000	0.446	3.065
	PADD I	0.003	0.418		1.304				0.219	1.944
	PADD II	0.036	0.276		0.102				0.153	0.567
	PADD III	0.001	0.146		0.142				0.058	0.347
	PADD IV	0.011	0.069		0.007				0.016	0.103
	PADD V	0.013	0.151		0.021				0.028	0.213
Industrial	US	0.054	0.81		0.357				0.889	2.110
	California	0.000	0.043		0.000				0.002	0.045
	Alaska	0.01	0.00002		0.004					0.014
	Hawaii		0.001		0.000					0.001
	49 State	0.054	0.767	0.000	0.357	0.000	0.000	0.000	0.802	1.980
	PADD I	0.001	0.116		0.219				0.281	0.617
	PADD II	0.026	0.176		0.111				0.285	0.598
	PADD III	0.003	0.193		0.004				0.218	0.418
	PADD IV	0.013	0.202		0.008				0.018	0.241
	PADD V	0.011	0.123		0.015				0.087	0.236

Category	Area	No. 1	L.S. Diesel	Diesel	No. 2 F.O.	Distillate F.O.	Total Distillate	Other Distillate	H.S. Diesel	Total*
Oil Company	US					0.685				0.685
	California					0.006				0.006
	Alaska					0.026				0.026
	Hawaii					0.000				0.000
	49 State	0.000	0.000	0.000	0.000	0.679	0.000	0.000	0.000	0.679
	PADD I					0.019				0.019
	PADD II					0.042				0.042
	PADD III					0.561				0.561
	PADD IV					0.029				0.029
	PADD V					0.034				0.034
Farm	US			3.08				0.089		3.169
	California			0.254				0.000		0.254
	Alaska			0.00003						0.000
	Hawaii			0.008						0.008
	49 State	0.000	0.000	2.826	0.000	0.000	0.000	0.089	0.000	2.915
	PADD I			0.389				0.044		0.433
	PADD II			1.572				0.040		1.612
	PADD III			0.549				0.003		0.552
	PADD IV			0.219				0.002		0.221
	PADD V			0.351				0.000		0.351
Electric Utility	US					0.793				0.793
	California					0.008				0.008
	Alaska					0.036				0.036
	Hawaii					0.09				0.090
	49 State	0.000	0.000	0.000	0.000	0.785	0.000	0.000	0.000	0.785
	PADD I					0.305				0.305
	PADD II					0.134				0.134
	PADD III					0.195				0.195
	PADD IV					0.009				0.009
	PADD V					0.151				0.151
Railroad	US					3.071				3.071
	California					0.189				0.189
	Alaska					0.004				0.004
	Hawaii									0.000
	49 State	0.000	0.000	0.000	0.000	2.882	0.000	0.000	0.000	2.882
	PADD I					0.5				0.500
	PADD II					1.233				1.233
	PADD III					0.686				0.686
	PADD IV					0.345				0.345
	PADD V					0.307				0.307
Vessel*	US					2.081				2.081
	California					0.101				0.101
	Alaska					0.08				0.080
	Hawaii					0.013				0.013
	49 State	0.000	0.000	0.000	0.000	1.980	0.000	0.000	0.000	1.980
	PADD I					0.49				0.490
	PADD II					0.301				0.301

Category	Area	No. 1	L.S. Diesel	Diesel	No. 2 F.O.	Distillate F.O.	Total Distillate	Other Distillate	H.S. Diesel	Total*
	PADD III					1.033				1.033
	PADD IV					0.0002				0.000
	PADD V					0.256				0.256
Military	US			0.18				0.054		0.234
	California			0.007				0.000		0.007
	Alaska			0.006				0.00005		0.006
	Hawaii			0.011						0.011
	49 State	0.000	0.000	0.173	0.000	0.000	0.000	0.054	0.000	0.227
	PADD I			0.041				0.029		0.070
	PADD II			0.015				0.021		0.036
	PADD III			0.009				0.000		0.009
	PADD IV			0.002				0.002		0.004
	PADD V			0.111				0.002		0.113
Construction	US					1.9				1.900
	California					0.194				0.194
	Alaska					0.007				0.007
	Hawaii					0.003				0.003
	49 State	0.000	0.000	0.000	0.000	1.706	0.000	0.000	0.000	1.706
	PADD I					0.511				0.511
	PADD II					0.549				0.549
	PADD III					0.394				0.394
	PADD IV					0.15				0.150
	PADD V					0.295				0.295
Other Off High	US					0.431				0.431
	California					0.022				0.022
	Alaska					0.007				0.007
	Hawaii					0.000				0.000
	49 State	0.000	0.000	0.000	0.000	0.409	0.000	0.000	0.000	0.409
	PADD I					0.159				0.159
	PADD II					0.059				0.059
	PADD III					0.123				0.123
	PADD IV					0.03				0.030
	PADD V	0.000				0.06				0.060

[a] Energy Information Administration. *Fuel Oil and Kerosene Sales 2000*. DOE/EIA-0535(00). Office of Oil and Gas, U.S. Department of Energy. Washington, D. C. September, 2001.

The information in Tables 7A-2 through 7A-7 was used to derive Table 7.1-21

Table 7A-2
1996 Off-highway Diesel Sulfur Levels from TRW (Niper)

Sample	Region	District	PADD	Use Category	Presumed Volume	Sulfur, ppm	Sulfur * Volume
39	Eastern	B1	1	SM	1,500,000	1700	2,550,000,000
40	Eastern	B1, D1	1	RR, SM	1,500,000	4000	6,000,000,000
41	Eastern	C2	1	TT	500,000	1800	900,000,000
42	Eastern	C1, E3	1	RR, SM	1,500,000	3700	5,550,000,000
43	Eastern	C2, E3	1	RR, SM	1,000,000	2900	2,900,000,000
45	Southern	D1	1	TT	750,000	4330	3,247,500,000
46	Southern	D1	1	TT	750,000	4900	3,675,000,000
47	Southern	D3	1	SM	137,500	9600	1,320,000,000
48	Eastern	D, B, C, A	1	SM, RR		1600	
					7,637,500		3,423
41	Eastern	C2	2	TT	500,000	1800	900,000,000
42	Central	C1, E3	2	RR, SM	275,000	3700	1,017,500,000
43	Central	C2, E3	2	RR, SM	275,000	2900	797,500,000
48	Eastern	D, B, C, A	2	SM, RR		1600	
49	Central	F1, E3	2	RR, SM	1,775,000	4200	7,455,000,000
50	Central	G	2			2050	
51	Central	G	2			1640	
					2,825,000		3,600
40	Southern	B1, D1	3	SM	1,500,000	4000	6,000,000,000
45	Southern	D1	3	TT	750,000	4330	3,247,500,000
46	Southern	D1	3	TT	750,000	4900	3,675,000,000
47	Southern	D3	3	SM	137,500	9600	1,320,000,000
48	Southern	D, B, C, A	3	RR, SM		1600	
					3,137,500		4,539
52	Rocky Mtn	K3, L3, M3	4	TT	412,500	4100	1,691,250,000
					412,500		4,100
52	Western	K3, L3, M3	5	TT	412,500	4100	1,691,250,000
53	Western	M1	5	TT	1,500,000	2700	4,050,000,000
					1,912,500		3,002
			National		15,925,000		3,641

Table 7A-3
1997 Off-highway Diesel Sulfur Levels from TRW (Niper)

Sample	Region	District	PADD	Use Category	Presumed Volume	Sulfur, ppm	Sulfur * Volume
47	Eastern	B	1			1900	
48	Eastern	B, D	1	SM		1200	
49	Eastern	B1	1	SM	1,500,000	1600	2,400,000,000
50	Eastern	B1, D1	1	RR, SM	2,250,000	4000	9,000,000,000
51	Eastern	C1, E3	1	RR, SM	750,000	4100	3,075,000,000
52	Eastern	C2	1	TT	750,000	2000	1,500,000,000
53	Eastern	C2, E3	1	RR, SM	750,000	3220	
					6,000,000		2,663
51	Central	C1, E3	2	RR, SM	1,025,000	4100	4,202,500,000
52	Central	C2	2	TT	500,000	2000	1,000,000,000
53	Central	C2, E3	2	RR, SM	775,000	3220	2,495,500,000
57	Southern	D1, G2	2	TT	1,000,000	1640	1,640,000,000
60	Central	F1, E3	2	RR, SM	1,775,000	3360	5,964,000,000
61	Central	G	2	RR		2160	
					2,775,000		2,740
48	Southern	B, D	3	SM		1200	
50	Southern	B1, D1	3	RR, SM	750,000	4000	3,000,000,000
55	Southern	D1	3	TT	750,000	5000	3,750,000,000
56	Southern	D1	3	TT	750,000	3460	2,595,000,000
57	Southern	D1, G2	3	TT	750,000	1640	1,230,000,000
58	Southern	D2	3	RR, SM	500,000	4800	2,400,000,000
59	Southern	D3	3	SM	137,500	10000	1,375,000,000
					3,637,500		3,945
63	Rocky Mtn	K3, L3, M3	4	TT	275,000	1000	275,000,000
					275,000		1,000
63	Western	K3, L3, M3	5	TT	550,000	1000	550,000,000
64	Western	M1, N1	5	TT	3,000,000	2500	7,500,000,000
					3,550,000		2,268
			National		16,237,500		2,849

Table 7A-4
1998 Off-highway Diesel Sulfur Levels from TRW (Niper)

Sample	Region	District	PADD	Use Category	Presumed Volume	Sulfur, ppm	Sulfur * Volume
43	Eastern	B	1	TT		1600	
44	Eastern	B2	1	SM	1,000,000	1540	1,540,000,000
45	Eastern	C2, E2	1		500,000	2600	1,300,000,000
48	Southern	D1	1	TT	750,000	4900	3,675,000,000
49	Southern	D1	1	RR, SM	750,000	3870	2,902,500,000
50	Southern	D1	1	TT	750,000	1300	975,000,000
51	Southern	D1, G2	1	RR, SM	750,000	10000	7,500,000,000
52	Southern	D3	1		137,500	4700	646,250,000
					4,637,500		3,998
45	Central	C2, E2	2		1,500,000	2600	3,900,000,000
50	Central	D1, G2	2	TT	1,000,000	1300	1,300,000,000
53	Central	F3	2		275,000	3700	1,017,500,000
					1,275,000		1,818
48	Southern	D1	3	TT	750,000	4900	3,675,000,000
49	Southern	D1	3	RR, SM	750,000	3870	2,902,500,000
50	Southern	D1	3	TT	750,000	1300	975,000,000
51	Southern	D1, G2	3	RR, SM	750,000	10000	7,500,000,000
52	Southern	D3	3		137,500	4700	646,250,000
					3,137,500		5,004
73	Rocky Mtn	K3, L3, M3	4	TT	275,000	3400	935,000,000
					275,000		3,400
73	Western	K3, L3, M3	5	TT	550,000	3400	1,870,000,000
74	Western	M2	5	TT	1,000,000	2900	2,900,000,000
					1,550,000		3,077
			National		10,875,000		3,886

Table 7A-5
1999 Off-highway Diesel Sulfur Levels from TRW (Niper)

Sample	Region	District	PADD	Use Category	Presumed Volume	Sulfur, ppm	Sulfur * Volume
65	Eastern	B2	1	SM	1,000,000	1560	1,560,000,000
66	Eastern	C3	1		137,500	4950	680,625,000
67	Southern	D1	1	SM, RR	750,000	4290	3,217,500,000
68	Southern	D1	1	TT	750,000	4590	3,442,500,000
69	Southern	D1	1	TT	750,000	4900	3,675,000,000
70	Southern	D1, E1, G2	1	TT	750,000	1200	900,000,000
71	Southern	D3	1	RR, SM	137,500	10000	1,375,000,000
					4,275,000		3,474
66	Eastern	C3	2		137,500	4950	680,625,000
70	Central	D1, E1, G2	2	TT	2,500,000	1200	3,000,000,000
72	Central	F3	2		275,000	4800	1,320,000,000
					2,912,500		1,717
44	Southern	D1	3	TT	750,000	4900	3,675,000,000
45	Southern	D1	3	SM, RR	750,000	4113	3,084,750,000
67	Southern	D1	3	SM, RR	750,000	4290	3,217,500,000
68	Southern	D1	3	TT	750,000	4590	3,442,500,000
69	Southern	D1	3	TT	750,000	4900	3,675,000,000
70	Southern	D1, E1, G2	3	TT	750,000	1200	900,000,000
71	Southern	D3	3	RR, SM	137,500	10000	1,375,000,000
					4,637,500		4,177
73	Rocky Mtn	K3, L3, M3	4	TT	275,000	2000	550,000,000
					275,000		2,000
73	Western	K3, L3, M3	5	TT	550,000	2000	1,100,000,000
74	Western	M2	5	TT	1,000,000	2100	2,100,000,000
					1,550,000		2,065
			National		13,650,000		3,148

Table 7A-6
2000 Off-highway Diesel Sulfur Levels from TRW (Niper)

Sample	Region	District	PADD	Use Category	Presumed Volume	Sulfur, ppm	Sulfur * Volume
37	Eastern	B	1			1370	
38	Eastern	B2	1	TT	1,000,000	3000	3,000,000,000
39	Eastern	B2	1	TT	1,000,000	2900	2,900,000,000
40	Eastern	B2	1	SM	1,000,000	1280	1,280,000,000
41	Eastern	C1	1	TT, RR	750,000	3600	2,700,000,000
42	Eastern	C2, E2	1		500,000	7200	3,600,000,000
43	Eastern	C3	1		137,500	4240	583,000,000
44	Southern	D1	1	TT	750,000	4900	3,675,000,000
45	Southern	D1	1	SM, RR	750,000	4113	3,084,750,000
46	Southern	D1, E1, G2	1	TT	750,000	1150	862,500,000
47	Southern	D2	1	TT	500,000	3100	1,550,000,000
48	Southern	D2	1	RR, SM	500,000	9800	4,900,000,000
49	Southern	D2	1	TT, RR	500,000	4440	2,220,000,000
50	Southern	D3	1		137,500	4800	660,000,000
51	Eastern	E1, C1	1	TT, RR	750,000	2600	1,950,000,000
					9,025,000		3,653
41	Eastern	C1	2	TT, RR	750,000	3600	2,700,000,000
42	Central	C2, E2	2		1,500,000	2200	3,300,000,000
43	Eastern	C3	2		137,500	4240	583,000,000
46	Central	D1, E1, G2	2	TT	2,500,000	1150	2,875,000,000
51	Central	E1, C1	2	TT, RR	2,250,000	2600	5,850,000,000
52	Central	F3	2		275,000	4120	1,133,000,000
53	Central	G1, E1	2	TT, RR	3,000,000	4720	14,160,000,000
					10,412,500		2,939
44	Southern	D1	3	TT	750,000	4900	3,675,000,000
45	Southern	D1	3	SM, RR	750,000	4113	3,084,750,000
46	Southern	D1, E1, G2	3	TT	750,000	1150	862,500,000
47	Southern	D2	3	TT	500,000	3100	1,550,000,000
48	Southern	D2	3	RR, SM	500,000	9800	4,900,000,000
49	Southern	D2	3	TT, RR	500,000	4440	2,220,000,000
50	Southern	D3	3		137,500	4800	660,000,000
					3,887,500		4,361
60	Rocky Mtn	K3	4	TT	275,000	2600	715,000,000
					275,000		2,600
1996 Off-highway Diesel Sulfur Levels from TRW (Niper)							
52	Western	K3, L3, M3	5	TT	412,500	4100	1,691,250,000
53	Western	M1	5	TT	1,500,000	2700	4,050,000,000
					1,912,500		3,002
			National		25,512,500		3,409

Table 7A-7

2001 Off-highway Diesel Sulfur Levels from TRW (Niper) 14 samples total

Sample	Region	District	PADD	Use Category	Presumed Volume	Sulfur, ppm	Sulfur * Volume
48	Eastern	B2	1	SM	1,000,000	1560	1,560,000,000
49	Eastern	B3	1	TT	275,000	1600	440,000,000
50	Eastern	C1	1	TT	750,000	3020	2,265,000,000
51	Eastern	C2, E2	1		1,000,000	3000	3,000,000,000
52	Eastern	C3	1		137,500	1360	187,000,000
53	Southern	D1	1	SM, RR	750,000	4330	3,247,500,000
54	Southern	D1	1	TT	750,000	4600	3,450,000,000
55	Southern	D3	1		137,500	4980	684,750,000
56	Southern	D3	1	TT	137,500	1800	247,500,000
					4,937,500		3,055
50	Eastern	C1	2	TT	750,000	3020	2,265,000,000
51	Central	C2, E2	2		1,000,000	3000	3,000,000,000
52	Central	C3	2		137,500	1360	187,000,000
57	Central	E4	2	TT	50,000	3100	155,000,000
58	Central	F3	2		275,000	4150	1,141,250,000
59	Central	G1, E1	2	TT, RR	3,000,000	4590	13,770,000,000
					5,212,500		3,936
53	Southern	D1	3	SM, RR	750,000	4330	3,247,500,000
54	Southern	D1	3	TT	750,000	4600	3,450,000,000
55	Southern	D3	3		137,500	4980	684,750,000
56	Southern	D3	3	TT	137,500	1800	247,500,000
					1,775,000		4,298
60	Rocky Mtn	K3	4		275,000	2340	643,500,000
					275,000		2,340
1996 Off-highway Diesel Sulfur Levels from TRW (Niper)							
52	Western	K3, L3, M3	5	TT	412,500	4100	1,691,250,000
53	Western	M1	5	TT	1,500,000	2700	4,050,000,000
					1,912,500		3,002
			National		14,112,500		3,516

Appendix 7B: Land-Based Nonroad Engine Growth Rate Based on Annual Energy Outlook 2002

Table 7.B-1
2000-2008 Composite Growth Factor for Land-Based Nonroad Engines
Based on Annual Energy Outlook 2002 (AEO2002)

End Use	2000 Land-Based Nonroad Diesel Demand (million gallons)	Fraction of Total	2000-2008 Multiplicative Growth Factor	Consumption Weighted Multiplicative Growth Factor	% Simple Annual Growth Rate	Source of Energy Consumption
Commercial	488	0.059	1.105	0.065	--	Diesel demand from Table 7.1-8;, Growth factor from AEO2002, Table 2, Commercial, Distillate Fuel
Industrial	1721	0.208	1.063	0.222	--	Diesel demand from Table 7.1-8; Growth factor from AEO2002, Table 2, Industrial, Distillate Fuel
Farm	3080	0.373	1.039	0.388	--	Diesel demand from Table 7.1-8; Growth factor from AEO2002, Table 32, Agriculture, Distillate Fuel
Construction	1805	0.219	1.138	0.249	--	Diesel demand from Table 7.1-8;, Growth factor from AEO2002, Table 32, Construction, Distillate Fuel
Railroad	29	0.004	1.083	0.004	--	Diesel demand from Table 7.1-8;, Growth factor from AEO2002, Table 7, Energy Use by Mode, Railroad
Military	153	0.019	1.000	0.019	--	Diesel demand from Table 7.1-8, Assumed no growth due to base closings and no information suggesting long term increases in training or emergency operations
Other Non-Highway	409	0.050	1.074	0.053	--	Diesel demand from Table 7.1-8, Growth factor from Table 7.1-15
Oil Company	342	0.041	1.074	0.044	--	Assumed same as Other Non-Highway
On-Highway	229	0.028	1.238	0.034	--	Diesel demand from Table 7.1-8; Growth factor from AEO2002, Table 7, Energy Use by Mode, Freight Trucks (over 10,000 lbs. GVWR.
Composite Average				**1.078**	**0.97**	

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CHAPTER 8: Estimated Aggregate Cost and Cost per Ton of Reduced Emissions

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CHAPTER 8: Estimated Aggregate Cost and Cost per Ton of Reduced Emissions

Our estimate of fixed and variable costs for new nonroad engines and equipment compliant with today's proposal are detailed in Chapter 6. Chapter 6 also contains a discussion of the operating savings and costs expected to result from the new low sulfur diesel fuels available to nonroad engines, locomotive engines, and marine engines. Our estimates of the costs to meet the proposed nonroad diesel fuel requirements can be found in Chapter 7. This chapter contains information on how the incremental costs for engines, the incremental operating costs, the incremental equipment costs, and the incremental fuel costs are aggregated to estimate the cost of the proposed program. The detailed information on the calculation for the cost per ton per pollutant is also included in this Chapter.

We have calculated the cost per ton of our proposed program based on the net present value of all costs incurred and all emission reductions generated over a 30 year time window following implementation of the program. This approach captures all of the costs and emissions reductions from our proposed program including those costs incurred and emissions reductions generated by the existing fleet. The baseline (i.e., the point of comparison) for this evaluation is the existing set of fuel and engine standards (i.e., unregulated fuel and the Tier 2/Tier 3 program). The 30 year time window chosen is meant to capture both the early period of the program when very few new engines that meet the proposed standards would be in the fleet, and the later period when essentially all engines would meet the proposed standards. Note that all costs and emission reductions presented here are 30 year numbers (net present values are 2007 through 2036, expressed in 2004). Elsewhere in this draft RIA we use numbers through 2030 (i.e., 2007 through 2030, expressed in 2004). As a result, net present values presented here will differ from net present values in other sections of this draft RIA.

8.1 Projected Sales and Cost Allocations

Projected nonroad engine and equipment sales estimates are used in several portions of this analysis. We have used two sources for our projected sales numbers – the PSR database for the 2000 model year, and our Nonroad Model.[1, 2] The PSR database has been used as the basis for our current fleet mix – i.e., what equipment types were sold in 2000 and with what horsepower engines. The sales estimates and growth rates used throughout this analysis are shown in Table 8.1-1.[3]

Table 8.1-1
Estimated 2000 Engine Sales and Future Sales Growth

Horsepower Range	2000 Model Year Sales	Annual Growth in Engines Sold	Linear Growth Rate
0<hp<25	119,159	4,116	3.7%
25≤hp<50	132,981	3,505	2.8%
50≤hp<75	93,914	2,046	2.3%
75≤hp<100	68,665	1,499	2.3%
100≤hp<175	112,340	2,321	2.2%
175≤hp<300	61,851	1,414	2.4%
300≤hp<600	34,095	436	1.3%
600≤hp≤750	2,752	50	1.9%
hp>750	2,785	51	1.9%
Total	628,542	15,438	2.5%

Because our proposed program would result in reductions in a number of important pollutants (i.e., NOx, PM, NMHC, and SOx), we have attempted to identify what costs are associated with what pollutant reductions. This apportionment of costs by pollutant allows us to calculate the average cost per ton of emission reduction that would be realized by this program. Deciding how to apportion costs can be difficult even in the case of technologies that, on the surface, seem to have an obvious split by which their costs should be attributed. For instance, we have apportioned 100 percent of the cost for CDPF technology to PM even though CDPFs are expected to reduce NMHC emissions significantly. Similary, we have apportioned 100 percent of the 500 ppm fuel program to SOx control even though it would also provide a significant PM reduction. In our proposed fuel program, the cost for reducing sulfur from uncontrolled levels to 15 ppm are apportioned to NOx+NMHC and PM because the 15 ppm sulfur level has been selected based on the needs of the control technology (i.e., NOx adsorber and CDPF). We have done this even though a significant SOx reduction would also be realized by the new 15 ppm fuel. We have noted throughout our discussion to which pollutant we have attributed costs, and Table 8.1-2 presents a summary of these allocations.

Table 8.1-2.
Summary of How Cost are Allocated Among Pollutants

Item		NOx+ NMHC	PM	SOx
Fuel Costs – incremental cent/gallon	3000 to 500 ppm fuel			100%
	3000 to 15 ppm fuel	50%	50%	
Operating Costs – Oil Change Savings	500 ppm fuel			100%
	15 ppm fuel	50%	50%	
Operating Costs – CDPF Maintenance	15 ppm fuel		100%	
Operating Costs – CDPF Regen (FE impact)	15 ppm fuel		100%	
Operating Costs – CCV Maintenance	2008+	50%	50%	
Engine Variable Costs	CDPF System		100%	
	NOx Adsorber System	100%		
	DOC		100%	
	Fuel Injection System	50%	50%	
	Regeneration System		100%	
	Cooled EGR	100%		
	Closed Crankcase Ventilation Sys	50%	50%	
Engine Fixed Costs – R&D	CDPF+NOx Adsorber	67%	33%	
	CDPF-only		100%	
	DOC-only		100%	
Engine Fixed Costs – Tooling	CDPF+NOx Adsorber	50%	50%	
	CDPF-only		100%	
	DOC-only		100%	
	Cooled EGR	100%		
Engine Fixed Costs – Certification	>75 hp	50%	50%	
	<75 hp 2008		100%	
	50-75 hp 2013		100%	
	25-50 hp 2013	50%	50%	
Equipment Variable Costs	>75 hp	50%	50%	
	<75 hp		100%	
Equipment Fixed Costs – Redesign	2008 standards		100%	
	2011, 2012, 2013 standards	50%	50%	
Equipment Fixed Costs – Operator Manuals	2008 standards		100%	
	2011, 2012, 2013 standards	50%	50%	

8.2 Aggregate Engine Costs

This section presents aggregate engine fixed costs (recovered costs) and variable costs. These costs were discussed in detail in Section 6.2.

8.2.1 Aggregate Engine Fixed Costs

In Chapter 6, Tables 6.2-4, 6.2-6, and 6.2-8 presented the aggregate engine fixed costs,[A] along with our best estimate of how those costs might be recovered (i.e., on what engines), for engine R&D, tooling, and certification, respectively. Table 8.2-1 presents the combined total of all engine fixed costs in the each of the indicated years and also shows to what pollutant these costs are attributed. Note that the cost allocations shown in Table 8.2-1 are not generated assuming any simple split of costs between NOx and PM control. Some engine fixed costs are solely attributed to PM control (e.g., costs associated with the proposed 2008 standards and costs associated with the proposed 2013 standards for 50 to 75 horsepower engines). Therefore, the costs presented in Table 8.2-1 for PM would not represent the total fixed costs of the program if there were no new NOx standards; the same is true of NOx costs if there were no new PM standards. Refer to Section 6.2 for detail on how we have estimated engine fixed costs and their recovery, and to Table 8.1-2 for how they are allocated among each pollutant.

[A] We have estimated a “recovered” cost for all engine and equipment fixed costs to present a per unit analysis of the cost of the proposal. In general, in environmental economics, it would be more conventional to simply count the total cost of the program (i.e., opportunity costs) in the year they occur. However, this approach would not directly estimate a per unit cost since fixed costs occur prior to implementation of the standards and, therefore, there are not yet any units certified as complying with the new standards to which the fixed costs can be attributed. As a result, we grow fixed costs until they can be “recovered” on complying units. Note that the approach used here results in a higher estimate of the total costs of the program since the recovered costs include a seven percent rate of return to the manufacturer.

Table 8.2-1
Aggregate Engine Fixed Costs (millions)

Year	Recovery of PM Costs	Recovery of NOx+NMHC Costs	Recovery of Fixed Costs
2004	$0.0	$0.0	$0.0
2005	$0.0	$0.0	$0.0
2006	$0.0	$0.0	$0.0
2007	$0.0	$0.0	$0.0
2008	$17.4	$0.0	$17.4
2009	$17.4	$0.0	$17.4
2010	$17.4	$0.0	$17.4
2011	$31.9	$14.7	$46.6
2012	$37.1	$19.9	$57.0
2013	$36.9	$21.2	$58.0
2014	$37.1	$35.2	$72.3
2015	$37.1	$35.2	$72.3
2016	$22.6	$20.5	$43.1
2017	$17.4	$15.3	$32.7
2018	$0.2	$14.0	$14.2
2019	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0
Total	$272.3	$175.9	$448.3
NPV 2004-2036	$210.7	$129.5	$340.2

We have assumed that all engine R&D expenditures occur over a five year span preceding the first year any emission control device is introduced into the market. Where a phase-in exists (e.g., for NOx standards on >75 horsepower engines), expenditures are assumed to occur over the five year span preceding the first year NOx adsorbers would be introduced, and then to continue during the phase-in years; the expenditures would be incurred in a manner consistent with the phase-in of the standard. All R&D expenditures are then recovered by the engine manufacturer over an identical time span following the introduction of the technology. We assume a seven percent rate of return for all R&D to reflect the time value of money.

We have assumed that all tooling and certification costs are incurred one year in advance of the new standard and are recovered over a five year period following implementation of the new standard; all tooling costs include a seven percent rate of return to reflect the time value of money.

We have calculated the net present value of the engine fixed costs over the 30 year period following implementation of the program as $340 million. This value assumes a three percent social discount rate and a 2004 date for promulgation of the final standards.

8.2.2 Aggregate Engine Variable Costs

Engine variable costs are discussed in detail in Section 6.2.2 of this Draft RIA. As explained there, we have generated cost estimation equations to calculate engine variable costs. These cost estimation equations are summarized in Table 6.4-2. Using these equations, we have calculated the engine variable costs during the years 2008 through 2036 as shown in Tables 8.2-2 and 8.2-3 (refer to Table 8.1-2 for how costs have been allocated to PM and NOx). Because of their nature, variable costs vary with sales. We have calculated the net present value of the variable costs over the 30 year period following implementation of the program (2007 through 2036) as $13.9 billion. This value assumes a three percent social discount rate.

Table 8.2-2
Aggregate Engine Variable Costs by Horsepower Category (millions)

Year	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<100	100<=hp<175	175<=hp<300	300<=hp<600	600<=hp<=750	>750hp	Total
2004	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2005	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2006	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2007	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2008	$0.0	$24.0	$18.8	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$62.8
2009	$20.5	$24.6	$19.2	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$64.2
2010	$20.0	$23.7	$18.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$62.1
2011	$20.5	$24.2	$18.7	$0.0	$0.0	$157.1	$106.5	$17.1	$18.8	$362.9
2012	$21.0	$24.7	$19.1	$99.7	$197.6	$160.0	$107.7	$17.4	$19.1	$666.2
2013	$21.5	$152.2	$101.8	$101.4	$200.9	$126.2	$84.3	$13.6	$15.3	$817.2
2014	$22.0	$155.2	$103.5	$102.1	$200.4	$161.9	$107.3	$17.4	$31.0	$900.8
2015	$22.5	$84.9	$80.0	$103.9	$203.6	$164.7	$108.4	$17.6	$31.4	$817.1
2016	$23.0	$122.4	$81.3	$105.6	$206.8	$167.5	$109.6	$17.9	$31.9	$866.0
2017	$23.5	$124.6	$82.6	$107.3	$210.0	$170.3	$110.8	$18.1	$32.3	$879.6
2018	$24.1	$126.9	$83.9	$109.0	$213.3	$173.2	$111.9	$18.4	$32.8	$893.3
2019	$24.6	$129.2	$85.2	$110.7	$216.5	$176.0	$113.1	$18.6	$33.2	$907.0
2020	$25.1	$131.4	$86.5	$112.4	$219.7	$178.8	$114.3	$18.9	$33.7	$920.7
2021	$25.6	$133.7	$87.9	$114.1	$222.9	$181.6	$115.4	$19.1	$34.1	$934.4
2022	$26.1	$136.0	$89.2	$115.8	$226.1	$184.4	$116.6	$19.4	$34.6	$948.1
2023	$26.6	$138.2	$90.5	$117.5	$229.3	$187.2	$117.8	$19.6	$35.0	$961.7
2024	$27.1	$140.5	$91.8	$119.2	$232.5	$190.0	$118.9	$19.9	$35.5	$975.4
2025	$27.6	$142.8	$93.1	$120.9	$235.7	$192.8	$120.1	$20.1	$35.9	$989.1
2026	$28.2	$145.0	$94.4	$122.6	$239.0	$195.6	$121.2	$20.4	$36.4	$1,002.8
2027	$28.7	$147.3	$95.7	$124.4	$242.2	$198.4	$122.4	$20.6	$36.8	$1,016.5
2028	$29.2	$149.6	$97.0	$126.1	$245.4	$201.2	$123.6	$20.9	$37.3	$1,030.2
2029	$29.7	$151.8	$98.4	$127.8	$248.6	$204.0	$124.7	$21.1	$37.7	$1,043.9
2030	$30.2	$154.1	$99.7	$129.5	$251.8	$206.8	$125.9	$21.4	$38.2	$1,057.5
2031	$30.7	$156.4	$101.0	$131.2	$255.0	$209.6	$127.1	$21.7	$38.6	$1,071.2
2032	$31.2	$158.7	$102.3	$132.9	$258.2	$212.4	$128.2	$21.9	$39.1	$1,084.9
2033	$31.7	$160.9	$103.6	$134.6	$261.4	$215.2	$129.4	$22.2	$39.5	$1,098.6
2034	$32.3	$163.2	$104.9	$136.3	$264.6	$218.0	$130.6	$22.4	$40.0	$1,112.3
2035	$32.8	$165.5	$106.2	$138.0	$267.9	$220.8	$131.7	$22.7	$40.4	$1,126.0
2036	$33.3	$167.7	$107.6	$139.7	$271.1	$223.6	$132.9	$22.9	$40.9	$1,139.6
NPV 2004-2036	$424.2	$1,983.0	$1,327.5	$1,652.8	$3,228.6	$2,734.7	$1,730.6	$287.8	$487.5	$13,874.3

Table 8.2-3
Aggregate Engine Variable Costs by Technology and by Pollutant (millions)

Year	Fuel System	Cooled EGR	CCV	DOC	CDPF System	CDPF Regen System	NOx Adsorber System	Total PM Costs	Total NOx+NMHC Costs	Total Costs
2004	$0.0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2005	$0.0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2006	$0.0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2007	$0.0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2008	$0.0	$0.0	$0.6	$62.2	$0.0	$0.0	$0.0	$62.5	$0.3	$62.8
2009	$0.0	$0.0	$0.6	$63.6	$0.0	$0.0	$0.0	$63.9	$0.3	$64.2
2010	$0.0	$0.0	$0.5	$61.7	$0.0	$0.0	$0.0	$61.9	$0.2	$62.1
2011	$0.0	$1.2	$7.2	$63.0	$186.0	$28.9	$76.6	$282.1	$80.8	$362.9
2012	$0.0	$1.2	$13.8	$64.3	$361.2	$72.6	$153.0	$505.7	$160.5	$666.2
2013	$55.0	$18.3	$12.1	$21.5	$435.4	$134.4	$140.5	$634.0	$183.2	$817.2
2014	$56.0	$19.6	$10.7	$22.0	$408.3	$126.7	$257.5	$600.2	$300.6	$900.8
2015	$43.0	$15.4	$10.9	$22.5	$387.0	$76.8	$261.5	$521.0	$296.1	$817.1
2016	$43.7	$15.7	$11.0	$23.0	$393.1	$113.9	$265.5	$565.3	$300.7	$866.0
2017	$44.5	$16.0	$11.2	$23.5	$399.2	$115.8	$269.5	$574.4	$305.3	$879.6
2018	$45.3	$16.2	$11.4	$24.1	$405.3	$117.7	$273.4	$583.4	$309.9	$893.3
2019	$46.0	$16.5	$11.5	$24.6	$411.4	$119.5	$277.4	$592.5	$314.5	$907.0
2020	$46.8	$16.8	$11.7	$25.1	$417.5	$121.4	$281.4	$601.6	$319.1	$920.7
2021	$47.6	$17.1	$11.9	$25.6	$423.6	$123.3	$285.4	$610.7	$323.7	$934.4
2022	$48.3	$17.4	$12.0	$26.1	$429.7	$125.1	$289.4	$619.8	$328.3	$948.1
2023	$49.1	$17.6	$12.2	$26.6	$435.8	$127.0	$293.4	$628.9	$332.9	$961.7
2024	$49.9	$17.9	$12.4	$27.1	$441.9	$128.9	$297.4	$638.0	$337.5	$975.4
2025	$50.6	$18.2	$12.5	$27.6	$448.0	$130.8	$301.4	$647.1	$342.1	$989.1
2026	$51.4	$18.5	$12.7	$28.2	$454.0	$132.6	$305.3	$656.1	$346.7	$1,002.8
2027	$52.2	$18.8	$12.9	$28.7	$460.1	$134.5	$309.3	$665.2	$351.3	$1,016.5
2028	$53.0	$19.1	$13.0	$29.2	$466.2	$136.4	$313.3	$674.3	$355.8	$1,030.2
2029	$53.7	$19.3	$13.2	$29.7	$472.3	$138.3	$317.3	$683.4	$360.4	$1,043.9
2030	$54.5	$19.6	$13.4	$30.2	$478.4	$140.1	$321.3	$692.5	$365.0	$1,057.5
2031	$55.3	$19.9	$13.5	$30.7	$484.5	$142.0	$325.3	$701.6	$369.6	$1,071.2
2032	$56.0	$20.2	$13.7	$31.2	$490.6	$143.9	$329.3	$710.7	$374.2	$1,084.9
2033	$56.8	$20.5	$13.9	$31.7	$496.7	$145.7	$333.3	$719.8	$378.8	$1,098.6
2034	$57.6	$20.8	$14.0	$32.3	$502.8	$147.6	$337.2	$728.9	$383.4	$1,112.3
2035	$58.3	$21.0	$14.2	$32.8	$508.9	$149.5	$341.2	$737.9	$388.0	$1,126.0
2036	$59.1	$21.3	$14.4	$33.3	$515.0	$151.4	$345.2	$747.0	$392.6	$1,139.6
NPV 2004-2036	$678.2	$244.2	$182.8	$620.3	$6,336.7	$1,788.2	$4,023.8	$9,297.9	$4,576.4	$13,874.3

8.3 Aggregate Equipment Costs

This section aggregates the amortized fixed and variable cost for equipment estimated in Section 6.3.

8.3.1 Aggregate Equipment Fixed Costs

In Table 6.3-4 we presented the aggregate equipment fixed costs, along with our best estimate of how those costs might be recovered, for equipment redesign and revisions to product literature. Table 8.3-1 presents aggregate equipment fixed costs and also shows to what pollutant these costs are attributed. Note that the cost allocations shown in Table 8.3-1 are not generated assuming any simple split of costs between NOx and PM control. Some equipment fixed costs are solely attributed to PM control (e.g., costs associated with the proposed 2008 standards and costs associated with the proposed 2013 standards for 50 to 75 horsepower engines). Therefore, the costs presented in Table 8.3-1 for PM would not represent the total fixed costs of the program if there were no new NOx standards; the same is true of NOx costs if there were no new PM standards. Refer to Section 6.3 for detail on how we have estimated equipment fixed costs and their recovery, and to Table 8.1-2 for how they are allocated among each pollutant.

Table 8.3-1
Aggregate Equipment Fixed Costs (millions)

Year	Recovery of PM Costs	Recovery of NOx+NMHC Costs	Recovery of Fixed Costs
2004	$0.0	$0.0	$0.0
2005	$0.0	$0.0	$0.0
2006	$0.0	$0.0	$0.0
2007	$0.0	$0.0	$0.0
2008	$4.9	$0.0	$4.9
2009	$4.9	$0.0	$4.9
2010	$4.9	$0.0	$4.9
2011	$26.1	$21.2	$47.3
2012	$39.8	$34.9	$74.7
2013	$49.1	$34.9	$84.1
2014	$58.5	$44.3	$102.8
2015	$58.5	$44.3	$102.8
2016	$58.5	$44.3	$102.8
2017	$58.5	$44.3	$102.8
2018	$53.6	$44.3	$98.0
2019	$53.6	$44.3	$98.0
2020	$53.6	$44.3	$98.0
2021	$32.4	$23.1	$55.5
2022	$18.7	$9.4	$28.1
2023	$9.4	$9.4	$18.7
2024	$0.0	$0.0	$0.0
Total	$584.9	$443.1	$1,028.0
NPV 2004-2036	$408.7	$308.0	$716.7

We have assumed that all equipment fixed costs (redesign and product literature) occur over a two year span preceding the first year any emission control device is introduced into the market. Where a phase-in exists (e.g., for NOx standards on >75 horsepower engines), expenditures are assumed to occur over the two year span preceding the first year NOx adsorbers would be introduced, and then to continue during the phase-in years; the expenditures would be incurred in a manner consistent with the phase-in of the standard. All expenditures are then recovered by the equipment manufacturer over 10 years following the introduction of the technology. We have assumed a seven percent rate of return for all equipment fixed costs to reflect the time value of money.

We have calculated the net present value of the equipment fixed costs over the 30 year period following implementation of the program as $720 million. This value assumes a three percent social discount rate and a 2004 date for promulgation of the final standards.

8.3.2 Aggregate Equipment Variable Costs

The equipment variable costs including sheet metal costs, mounting hardware, labor, etc. were estimated by horsepower category in Section 6.3. The variable costs were aggregated by multiplying the cost per unit within each horsepower category by the projected sales of that horsepower category. The aggregate equipment variable costs through 2036 are presented in Table 8.3-2. Table 8.3-3 shows the total aggregate equipment variable costs allocated by pollutant (refer to Table 8.1-2 for how costs have been allocated to PM and NOx).

Table 8.3-2
Aggregate Equipment Variable Costs by Horsepower Category (millions)

Year	0<hp<25	25≤hp<50	50≤hp<75	75≤hp<100	100≤hp<175	175≤hp<300	300≤hp<600	600≤hp≤750	>750hp	Total
2004	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2005	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2006	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2007	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2008	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2009	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2010	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2011	$0.0	$0.0	$0.0	$0.0	$0.0	$5.4	$5.2	$0.5	$0.4	$11.5
2012	$0.0	$0.0	$0.0	$4.8	$7.8	$5.5	$5.3	$0.5	$0.4	$24.2
2013	$0.0	$3.2	$2.1	$4.8	$7.9	$5.6	$5.4	$0.5	$0.4	$29.9
2014	$0.0	$3.2	$2.2	$4.9	$8.0	$5.7	$5.4	$0.5	$0.8	$30.8
2015	$0.0	$3.3	$2.2	$5.0	$8.2	$5.8	$5.5	$0.5	$0.8	$31.2
2016	$0.0	$3.4	$2.3	$5.1	$8.3	$5.9	$5.5	$0.5	$0.8	$31.7
2017	$0.0	$3.4	$2.3	$5.2	$8.4	$6.0	$5.6	$0.5	$0.8	$32.2
2018	$0.0	$3.5	$2.3	$5.2	$8.6	$6.1	$5.7	$0.5	$0.8	$32.7
2019	$0.0	$3.6	$2.4	$5.3	$8.7	$6.2	$5.7	$0.5	$0.8	$33.2
2020	$0.0	$3.6	$2.4	$5.4	$8.8	$6.3	$5.8	$0.5	$0.8	$33.7
2021	$0.0	$3.7	$2.4	$5.5	$8.9	$6.4	$5.8	$0.5	$0.9	$34.1
2022	$0.0	$3.7	$2.5	$5.6	$9.1	$6.5	$5.9	$0.5	$0.9	$34.6
2023	$0.0	$3.8	$2.5	$5.7	$9.2	$6.6	$6.0	$0.5	$0.9	$35.1
2024	$0.0	$3.9	$2.5	$5.7	$9.3	$6.7	$6.0	$0.6	$0.9	$35.6
2025	$0.0	$3.9	$2.6	$5.8	$9.5	$6.8	$6.1	$0.6	$0.9	$36.1
2026	$0.0	$4.0	$2.6	$5.9	$9.6	$6.9	$6.1	$0.6	$0.9	$36.6
2027	$0.0	$4.1	$2.7	$6.0	$9.7	$7.0	$6.2	$0.6	$0.9	$37.1
2028	$0.0	$4.1	$2.7	$6.1	$9.8	$7.1	$6.2	$0.6	$0.9	$37.5
2029	$0.0	$4.2	$2.7	$6.1	$10.0	$7.2	$6.3	$0.6	$0.9	$38.0
2030	$0.0	$4.2	$2.8	$6.2	$10.1	$7.3	$6.4	$0.6	$1.0	$38.5
2031	$0.0	$4.3	$2.8	$6.3	$10.2	$7.4	$6.4	$0.6	$1.0	$39.0
2032	$0.0	$4.4	$2.8	$6.4	$10.4	$7.5	$6.5	$0.6	$1.0	$39.5
2033	$0.0	$4.4	$2.9	$6.5	$10.5	$7.6	$6.5	$0.6	$1.0	$40.0
2034	$0.0	$4.5	$2.9	$6.6	$10.6	$7.7	$6.6	$0.6	$1.0	$40.5
2035	$0.0	$4.6	$2.9	$6.6	$10.7	$7.8	$6.7	$0.6	$1.0	$40.9
2036	$0.0	$4.6	$3.0	$6.7	$10.9	$7.9	$6.7	$0.6	$1.0	$41.4
NPV 2004-2036	$0.0	$50.9	$33.6	$79.5	$129.3	$96.8	$88.1	$8.0	$12.1	$498.3

Table 8.3-3
Aggregate Equipment Variable Costs by Pollutant (millions)

Year	PM Costs	NOx+NMHC Costs	Total
2008	$0.0	$0.0	$0.0
2009	$0.0	$0.0	$0.0
2010	$0.0	$0.0	$0.0
2011	$5.7	$5.7	$11.5
2012	$12.1	$12.1	$24.2
2013	$17.6	$12.3	$29.9
2014	$18.1	$12.7	$30.8
2015	$18.4	$12.9	$31.2
2016	$18.7	$13.1	$31.7
2017	$19.0	$13.2	$32.2
2018	$19.3	$13.4	$32.7
2019	$19.5	$13.6	$33.2
2020	$19.8	$13.8	$33.7
2021	$20.1	$14.0	$34.1
2022	$20.4	$14.2	$34.6
2023	$20.7	$14.4	$35.1
2024	$21.0	$14.6	$35.6
2025	$21.3	$14.8	$36.1
2026	$21.6	$15.0	$36.6
2027	$21.9	$15.2	$37.1
2028	$22.2	$15.4	$37.5
2029	$22.5	$15.6	$38.0
2030	$22.8	$15.8	$38.5
2031	$23.1	$16.0	$39.0
2032	$23.3	$16.1	$39.5
2033	$23.6	$16.3	$40.0
2034	$23.9	$16.5	$40.5
2035	$24.2	$16.7	$40.9
2036	$24.5	$16.9	$41.4
NPV 2004-2036	$291.4	$206.9	$498.3

8.4 Aggregate Fuel Costs and Other Operating Costs

Aggregate costs presented here are used in the calculation of costs per ton of emissions that would be reduced by the proposed standards for nonroad fuel and engines. We are proposing a 500 ppm sulfur cap on nonroad, locomotive, and marine fuels beginning in 2007. In Section 8.4.2 we summarize the costs for this program as if it remained in place for 30 years, even though it would be supplanted by the second step of our fuel program in 2010.

We are also proposing a second step in the fuel program that would cap nonroad fuel sulfur levels at 15 ppm beginning in 2010. This fuel program enables the introduction of advanced emission control technologies including CDPFs and NOx adsorbers. The combination of the two-step fuel program and the new diesel engine standards represents the total Tier 4 program for nonroad diesel engines and fuel proposed today. In Section 8.4.1 we present our estimate of the annual and total costs for this complete program beginning in 2007 and continuing for 30 years.

8.4.1 Aggregate Fuel Costs

Fuel costs are developed on a cents per gallon basis. Chapter 7 contains a description of the development of fuel costs for the proposed fuel program. Table 8.4-1 contains a summary of cent/gallon fuel costs, estimated fuel volumes for nonroad, locomotive, and marine, and the aggregate fuel costs through 2036 for the proposed two-step fuel program. Table 8.4-2 shows the same information assuming the proposed 500 ppm fuel program remained in place indefinitely and no new engine standards were implemented.

Table 8.4-1
Aggregate Fuel Costs of the Proposed Two-Step Fuel Program (millions)

	Aggregate Fuel Costs of Proposed Two-Step Fuel Program							
	Affected Volume for 500 ppm (gallons)*			Affected Volume for 15 ppm (gallons)*		Aggregate Fuel Costs		
Year	2007-2010 at $/gal cost of $0.025	2010-2014 at $/gal cost of $0.026	2014+ at $/gal cost of $0.024	2010-2014 at $/gal cost of $0.048	2014+ at $/gal cost of $0.048	500 ppm	15 ppm	Total
2004	0	0	0	0	0	$0	$0	$0
2005	0	0	0	0	0	$0	$0	$0
2006	0	0	0	0	0	$0	$0	$0
2007	5,449	0	0	0	0	$136	$0	$136
2008	9,504	0	0	0	0	$238	$0	$238
2009	9,671	0	0	0	0	$242	$0	$242
2010	4,099	2,892	0	3,495	0	$178	$168	$345
2011	0	5,034	0	6,124	0	$131	$294	$425
2012	0	5,088	0	6,256	0	$132	$300	$433
2013	0	5,137	0	6,389	0	$134	$307	$440
2014	0	2,162	2,369	2,717	4,461	$113	$345	$458
2015	0	0	4,093	0	7,803	$98	$375	$473
2016	0	0	4,136	0	7,957	$99	$382	$481
2017	0	0	4,170	0	8,111	$100	$389	$489
2018	0	0	4,203	0	8,265	$101	$397	$498
2019	0	0	4,238	0	8,419	$102	$404	$506
2020	0	0	4,268	0	8,573	$102	$412	$514
2021	0	0	4,311	0	8,727	$103	$419	$522
2022	0	0	4,354	0	8,881	$104	$426	$531
2023	0	0	4,397	0	9,035	$106	$434	$539
2024	0	0	4,441	0	9,190	$107	$441	$548
2025	0	0	4,485	0	9,344	$108	$448	$556
2026	0	0	4,530	0	9,497	$109	$456	$565
2027	0	0	4,575	0	9,650	$110	$463	$573
2028	0	0	4,621	0	9,803	$111	$471	$581
2029	0	0	4,668	0	9,956	$112	$478	$590
2030	0	0	4,715	0	10,110	$113	$485	$598
2031	0	0	4,763	0	10,263	$114	$493	$607
2032	0	0	4,811	0	10,416	$115	$500	$615
2033	0	0	4,859	0	10,569	$117	$507	$624
2034	0	0	4,908	0	10,723	$118	$515	$632
2035	0	0	4,958	0	10,876	$119	$522	$641
2036	0	0	5,008	0	11,029	$120	$529	$650
NPV 2004-2036	25,206	16,077	54,791	19,763	112,851	$2,363	$6,366	$8,729

* Note that “Affected Volumes” for 500 ppm and 15 ppm are taken from Table 7.1-35.

Table 8.4-2
Aggregate Fuel Costs for the 500 ppm Fuel Program (millions)

Year	Aggregate Fuel Costs of 500 ppm Fuel Program		
	Affected Volume for 500 ppm (gallons)*		Aggregate Fuel Costs
	2007-2010 at $/gal cost of $0.025	2010+ at $/gal cost of $0.024	Total
2004	0	0	$0
2005	0	0	$0
2006	0	0	$0
2007	5,449	0	$136
2008	9,504	0	$238
2009	9,671	0	$242
2010	4,099	6,387	$256
2011	0	11,158	$268
2012	0	11,344	$272
2013	0	11,526	$277
2014	0	11,709	$281
2015	0	11,895	$285
2016	0	12,092	$290
2017	0	12,281	$295
2018	0	12,468	$299
2019	0	12,657	$304
2020	0	12,841	$308
2021	0	13,038	$313
2022	0	13,235	$318
2023	0	13,432	$322
2024	0	13,630	$327
2025	0	13,829	$332
2026	0	14,027	$337
2027	0	14,226	$341
2028	0	14,425	$346
2029	0	14,624	$351
2030	0	14,825	$356
2031	0	15,025	$361
2032	0	15,227	$365
2033	0	15,429	$370
2034	0	15,631	$375
2035	0	15,834	$380
2036	0	16,037	$385
NPV 2004-2036	25,206	203,483	$5,514

* Note that the 2010+ gallons shown here are the summation of the 2010-2014 and 2014+ columns for both 500 ppm and 15 ppm fuel shown in Table 8.4-1 because there would be no introduction of 15 ppm fuel under the 500 ppm fuel program.

8.4.2 Aggregate Oil Change Maintenance Savings

Maintenance savings associated with extended oil change intervals are developed on a cents per gallon basis. Section 6.2.3 contains a description of the development of maintenance savings for the proposed program. Table 8.4-3 contains a summary of the maintenance savings and estimated fuel volumes for nonroad, locomotive, and marine through 2036 for the proposed two-step fuel program. Also presented in Table 8.4-3 are the maintenance savings of the 500 ppm fuel program assuming it remained in place indefinitely and no new engine standards were implemented. Note that the nonroad volumes shown in Table 8.4-3 under the 500 ppm fuel program are the summation of the two columns of nonroad volumes shown under the proposed fuel program (500 ppm during 2007 through part of 2010 and 15 ppm for the remainder of 2010 and beyond). The cent per gallon savings for locomotive and marine shown in Table 8.4-3 are taken from Table 6.2-26 (see also Table 6.4-3) while the cent per gallon savings shown for nonroad are taken from the discussion in section 6.2.3.1 (these values can also be derived using data shown in Table 6.2-26 by weighting the cent per gallon savings within each horsepower range by the fuel use weighting for that horsepower range – the summation of these weighted values for all horsepower ranges is 3.3 cents per gallon for 15 ppm fuel and 3.0 cents per gallon for 500 ppm fuel).

Table 8.4-3
Oil Change Maintenance Savings Associated with the Proposed Two-Step and the 500 ppm Fuel Programs (millions)

	Aggregate Maintenance Savings of Proposed Fuel Program						Aggregate Maintenance Savings of 500 ppm Fuel Program		
	500 ppm Volumes		15 ppm Volume	Aggregate Maintenance Savings			500 ppm Volume		Aggregate Maintenance Savings
Year	Nonroad Volume* at $/gal savings of $0.030	Loco&Marine Volume* at $/gal savings of $0.011	Nonroad Volume* at $/gal savings of $0.033	500 ppm	15 ppm	Total	Nonroad Volume* at $/gal savings of $0.030	Loco&Marine Volume* at $/gal savings of $0.011	Total
2004	0	0	0	$0	$0	$0	0	0	$0
2005	0	0	0	$0	$0	$0	0	0	$0
2006	0	0	0	$0	$0	$0	0	0	$0
2007	3,298	1,780	0	-$118	$0	-$118	3,298	1,780	-$118
2008	5,788	3,073	0	-$206	$0	-$206	5,788	3,073	-$206
2009	5,923	3,100	0	-$210	$0	-$210	5,923	3,100	-$210
2010	2,524	3,127	3,533	-$110	-$115	-$225	6,057	3,127	-$215
2011	0	3,416	6,025	-$38	-$196	-$234	6,025	3,416	-$217
2012	0	3,441	6,156	-$38	-$200	-$239	6,156	3,441	-$221
2013	0	3,462	6,288	-$39	-$205	-$243	6,288	3,462	-$225
2014	0	3,484	6,419	-$39	-$209	-$248	6,419	3,484	-$229
2015	0	3,484	7,545	-$39	-$246	-$284	7,545	3,484	-$263
2016	0	3,510	7,700	-$39	-$251	-$290	7,700	3,510	-$268
2017	0	3,548	7,853	-$40	-$256	-$295	7,853	3,548	-$273
2018	0	3,576	8,006	-$40	-$261	-$300	8,006	3,576	-$278
2019	0	3,604	8,159	-$40	-$266	-$306	8,159	3,604	-$283
2020	0	3,634	8,312	-$40	-$270	-$311	8,312	3,634	-$287
2021	0	3,658	8,465	-$41	-$275	-$316	8,465	3,658	-$292
2022	0	3,695	8,619	-$41	-$280	-$322	8,619	3,695	-$297
2023	0	3,732	8,772	-$42	-$285	-$327	8,772	3,732	-$302
2024	0	3,770	8,925	-$42	-$290	-$332	8,925	3,770	-$307
2025	0	3,808	9,078	-$42	-$295	-$338	9,078	3,808	-$312
2026	0	3,846	9,231	-$43	-$300	-$343	9,231	3,846	-$317
2027	0	3,885	9,383	-$43	-$305	-$349	9,383	3,885	-$322
2028	0	3,924	9,535	-$44	-$310	-$354	9,535	3,924	-$327
2029	0	3,964	9,687	-$44	-$315	-$359	9,687	3,964	-$332
2030	0	4,005	9,839	-$45	-$320	-$365	9,839	4,005	-$337
2031	0	4,046	9,992	-$45	-$325	-$370	9,992	4,046	-$342
2032	0	4,087	10,144	-$46	-$330	-$376	10,144	4,087	-$347
2033	0	4,129	10,296	-$46	-$335	-$381	10,296	4,129	-$352
2034	0	4,171	10,448	-$46	-$340	-$386	10,448	4,171	-$357
2035	0	4,214	10,600	-$47	-$345	-$392	10,600	4,214	-$362
2036	0	4,257	10,752	-$47	-$350	-$397	10,752	4,257	-$367
NPV 2004-2036	**15,383**	**65,449**	**128,702**	**-$1,186**	**-$4,188**	**-$5,374**	**144,086**	**65,449**	**-$5,009**

* Note that volumes are taken from Table 7.1-34 and are expressed in millions of gallons (volumes here do not include highway spillover volumes). Factors of 5/12 (Jan through May) and 7/12 (Jun through Dec) have been used in this table during transition years.

8.4.3 Aggregate CDPF & CCV Maintenance Costs and CDPF Regeneration Costs

Maintenance costs associated with CDPF maintenance and CCV maintenance are developed on a cents per gallon basis. Section 6.2.3 contains a description of the development of maintenance costs for the proposed program. Table 8.4-4 contains a summary of the maintenance costs and estimated fuel volumes for CDPF and CCV equipped engines through 2036 for the proposed two-step fuel program. Note that there are no maintenance costs or CDPF regeneration costs associated with the 500 ppm fuel program because that program has no new engine standards and, therefore, neither CDPF nor CCV hardware would be added to new engines. The fuel volumes shown in Table 8.4-4 differ from those shown in Tables 8.4-1 through 8.4-3 because the volumes of importance for maintenance costs are not volumes consumed by nonroad engines but rather volumes consumed by CDPF and CCV equipped engines (i.e., new engines that comply with the proposed standards). The CDPF volumes shown in Table 8.4-4 contain some highway spillover volumes so they do not match the nonroad volumes of Tables 8.4-1 through Table 8.4-3 even in the later years. The volumes shown for <75 horsepower engines are used only for CCV maintenance costs during the years from 2008 through 2012 after which time their volumes are captured by the CDPF volumes shown in the Table.

The cent per gallon costs shown for CDPF maintenance are taken from Table 6.2-27. The value can be derived using data shown in Table 6.2-26 by weighting the cent per gallon savings within each horsepower range by the fuel use weighting for that horsepower range – the summation of these weighted values for all horsepower ranges is 0.6 cents per gallon; note that weighting these values to reflect the phase-in schedule is not necessary since the volume of fuel already reflects this weighting. The cent per gallon costs shown for CCV maintenance are taken from Table 6.2-28, again doing a weighting for each horsepower range using the fuel use weightings shown in Table 6.2-28 (note that these fuel use weightings include the turbo-charged fraction shown in Table 6.2-28 because only turbo-charged engines would be adding the CCV system). Because the volumes shown for <75 horsepower engines includes volumes burned by non-turbo charged engines, it is necessary to weight the cent per gallon value by the phase-in schedule of the proposed standards; as a result, this value does not remain constant until 2013 and beyond. The cent per gallon costs shown for CDPF regeneration are taken from Table 6.4-3. Because of the phase-in schedule of the standards and the different fuel economy impacts of engines equipped with both a CDPF and a NOx adsorber (1 percent) versus a CDPF-only (2%), this value varies during the phase-in years before leveling off at a fleetwide average of 0.77 cents per gallon.

Table 8.4-4
CDPF & CCV Maintenance Costs and CDPF Regeneration Costs Associated with the Proposed Two-Step Fuel Program (millions)

						Aggregate Maintenance Costs of Proposed Fuel Program			
Year	Fuel Volume in CDPF engines*	Fuel Volume in <75hp engines during 2008-2012*	CDPF Maintenance CDPF-fleet weighted $/gal cost	CDPF Regeneration CDPF-fleet weighted $/gal cost**	CCV Maintenance CCV-fleet weighted $/gal cost	CDPF Maintenance	CDPF Regeneration	CCV Maintenance	Total
2004	0	0				$0	$0	$0	$0
2005	0	0				$0	$0	$0	$0
2006	0	0				$0	$0	$0	$0
2007	0	0				$0	$0	$0	$0
2008	0	163			$0.0004	$0	$0	$0	$0
2009	0	316			$0.0004	$0	$0	$0	$0
2010	0	477			$0.0004	$0	$0	$0	$0
2011	450	644	$0.0060	$0.0047	$0.0012	$3	$2	$1	$6
2012	1,310	818	$0.0060	$0.0073	$0.0017	$8	$10	$4	$21
2013	2,255	0	$0.0060	$0.0099	$0.0017	$13	$22	$4	$39
2014	3,249	0	$0.0060	$0.0077	$0.0017	$19	$25	$6	$50
2015	4,230	0	$0.0060	$0.0077	$0.0017	$25	$33	$7	$65
2016	5,172	0	$0.0060	$0.0077	$0.0017	$31	$40	$9	$80
2017	6,064	0	$0.0060	$0.0077	$0.0017	$36	$47	$11	$94
2018	6,880	0	$0.0060	$0.0077	$0.0017	$41	$53	$12	$106
2019	7,628	0	$0.0060	$0.0077	$0.0017	$46	$59	$13	$118
2020	8,314	0	$0.0060	$0.0077	$0.0017	$50	$64	$14	$129
2021	8,936	0	$0.0060	$0.0077	$0.0017	$53	$69	$16	$138
2022	9,511	0	$0.0060	$0.0077	$0.0017	$57	$74	$17	$147
2023	10,041	0	$0.0060	$0.0077	$0.0017	$60	$78	$17	$155
2024	10,540	0	$0.0060	$0.0077	$0.0017	$63	$82	$18	$163
2025	11,011	0	$0.0060	$0.0077	$0.0017	$66	$85	$19	$170
2026	11,445	0	$0.0060	$0.0077	$0.0017	$68	$89	$20	$177
2027	11,834	0	$0.0060	$0.0077	$0.0017	$71	$92	$21	$183
2028	12,183	0	$0.0060	$0.0077	$0.0017	$73	$94	$21	$188
2029	12,516	0	$0.0060	$0.0077	$0.0017	$75	$97	$22	$194
2030	12,836	0	$0.0060	$0.0077	$0.0017	$77	$99	$22	$198
2031	13,165	0	$0.0060	$0.0077	$0.0017	$79	$102	$23	$204
2032	13,502	0	$0.0060	$0.0077	$0.0017	$81	$105	$23	$209
2033	13,848	0	$0.0060	$0.0077	$0.0017	$83	$107	$24	$214
2034	14,203	0	$0.0060	$0.0077	$0.0017	$85	$110	$25	$220
2035	14,567	0	$0.0060	$0.0077	$0.0017	$87	$113	$25	$225
2036	14,940	0	$0.0060	$0.0077	$0.0017	$89	$116	$26	$231
NPV 2004-2036	**124,535**	**1,986**				**$745**	**$966**	**$218**	**$1,929**

*Note that fuel used in CDPF engines includes some highway spillover fuel. Refer to Table 7.1-34 for totoal nonroad volumes including highway spillover volumes; CDPF volumes are less than that total volume even in 2036 (14,940 vs. 15,626 million gallons) because some pre-control engines would still remain in the fleet. Note that fuel volumes in <75hp engines are used for CCV maintenance costs from 2008 to 2012, after which time their volumes are captured in the CDPF volumes.

**CDPF Regeneration $/gal costs change due to different fuel economy impacts with a NOx adsorber (1%) and without a NOx adsorber (2%) matched with the phase-in schedules of the proposed standards.

8.4.4 Summary of Aggregate Operating Costs

The net operating costs include the incremental costs for fuel (Table 8.4-1), costs for oil change maintenance savings (Table 8.4-3 for the proposed fuel program), and costs for CDPF maintenance, CCV maintenance, and CDPF regeneration (Table 8.4-4). The results of this summation for the proposed two-step fuel program are shown in Table 8.4-5. The oil change maintenance savings, CDPF and CCV maintenance costs, and CDPF regeneration costs are added together in Table 8.4-5 and presented as "Net Maintenance Costs." The net maintenance costs are presented as negative values, thus, they represent a net savings. The "Net Operating Cost" is the sum of the incremental fuel costs (both the 500 ppm fuel for nonroad, locomotive, and marine from 2007 through 2010, 500 ppm fuel for locomotive and marine in 2010 and beyond, and 15 ppm fuel for nonroad in 2010 and beyond) and the net maintenance costs. Table 8.4-5 also presents the allocation of these costs to each pollutant (refer to Table 8.1-2 for how these costs have been allocated). The sum of the SOx cost, the PM cost, and the NOx+NMHC cost is the value presented in the "Net Operating Cost" column. As shown in the table, the net present value during the period 2004 through 2036 of the proposed two-step fuel program is $5.3 billion using a three percent social discount rate, consisting of $8.7 billion in incremental fuel costs and $3.4 billion in net maintenance savings.

Table 8.4-6 presents the net operating costs associated with the 500 ppm fuel program. The costs presented in Table 8.4-6 include the incremental costs for fuel (Table 8.4-2), and costs for oil change maintenance savings (Table 8.4-3 for the 500 ppm fuel program). The oil change maintenance savings are presented in the table as "Net Maintenance Costs," and, thus, represent a net savings. The "Net Operating Cost" is the sum of the incremental fuel costs and the net maintenance costs. Table 8.4-6 also presents the allocation of these costs to each pollutant (refer to Table 8.1-2 for how these costs have been allocated). The costs shown in Table 8.4-6 assume the 500 ppm fuel program remains in place indefinitely. As a result, no new NOx and/or PM standards would be implemented. The 500 ppm fuel would result in large SOx reductions and, by comparison, smaller but still important PM reductions. Since the largest reduction is in SOx emissions, we have simply attributed all costs for the 500 ppm fuel program to SOx for our cost per ton calculations. Note that our emissions inventory projections and our benefits analysis include these PM reductions. We have also presented the SOx costs with maintenance savings (i.e., the net total cost) and without maintenance savings (i.e., the incremental fuel cost) so that a cost per ton can be calculated with and without the maintenance savings.

Table 8.4-5
Aggregate Net Operating Costs Associated with the Proposed Two-Step Fuel Program (millions)

	Aggregate Net Operating Costs of the Proposed Two-Step Fuel Program							
Year	500 ppm Fuel Costs	15 ppm Fuel Costs	Total Fuel Costs	Net Maintenance Costs	Net Operating Cost	SOx Cost	PM Cost	NOx+NMHC Cost
2004	$0	$0	$0	$0	$0	$0	$0	$0
2005	$0	$0	$0	$0	$0	$0	$0	$0
2006	$0	$0	$0	$0	$0	$0	$0	$0
2007	$136	$0	$136	-$118	$18	$18	$0	$0
2008	$238	$0	$238	-$206	$32	$31	$0	$0
2009	$242	$0	$242	-$210	$31	$31	$0	$0
2010	$178	$168	$345	-$225	$121	$68	$26	$26
2011	$131	$294	$425	-$228	$197	$93	$54	$50
2012	$132	$300	$433	-$218	$215	$94	$69	$52
2013	$134	$307	$440	-$204	$236	$95	$89	$53
2014	$113	$345	$458	-$197	$260	$74	$115	$71
2015	$98	$375	$473	-$219	$254	$59	$126	$68
2016	$99	$382	$481	-$210	$271	$60	$141	$70
2017	$100	$389	$489	-$201	$288	$61	$155	$72
2018	$101	$397	$498	-$194	$304	$61	$168	$74
2019	$102	$404	$506	-$188	$318	$62	$181	$76
2020	$102	$412	$514	-$182	$332	$62	$192	$78
2021	$103	$419	$522	-$178	$344	$63	$202	$79
2022	$104	$426	$531	-$175	$356	$63	$212	$81
2023	$106	$434	$539	-$172	$367	$64	$221	$83
2024	$107	$441	$548	-$169	$378	$65	$229	$85
2025	$108	$448	$556	-$168	$389	$65	$237	$86
2026	$109	$456	$565	-$166	$398	$66	$245	$88
2027	$110	$463	$573	-$166	$407	$67	$252	$89
2028	$111	$471	$581	-$166	$416	$67	$258	$91
2029	$112	$478	$590	-$166	$424	$68	$264	$92
2030	$113	$485	$598	-$166	$432	$69	$270	$94
2031	$114	$493	$607	-$167	$440	$69	$276	$95
2032	$115	$500	$615	-$167	$449	$70	$282	$97
2033	$117	$507	$624	-$167	$457	$71	$288	$98
2034	$118	$515	$632	-$167	$466	$71	$295	$100
2035	$119	$522	$641	-$167	$474	$72	$301	$101
2036	$120	$529	$650	-$166	$483	$73	$308	$103
NPV 2004-2036	**$2,363**	**$6,366**	**$8,729**	**-$3,445**	**$5,284**	**$1,177**	**$2,909**	**$1,198**

Note: for fuel costs see Table 8.4-1; for maintenance costs see Tables 8.4-3 and 8.4-4; for cost allocations by pollutant see Table 8.1-2.

Table 8.4-6
Aggregate Net Operating Costs Associated with the 500 ppm Fuel Program (millions)

	Aggregate Net Operating Costs of 500 ppm Fuel Program				
Year	Total Fuel Costs	Net Maintenance Costs	Net Operating Cost	SOx Cost w/ Maintenance Savings	SOx Cost w/o Maintenance Savings
2004	$0	$0	$0	$0	$0
2005	$0	$0	$0	$0	$0
2006	$0	$0	$0	$0	$0
2007	$136	-$118	$18	$18	$136
2008	$238	-$206	$31	$31	$238
2009	$242	-$210	$31	$31	$242
2010	$256	-$215	$41	$41	$256
2011	$268	-$217	$51	$51	$268
2012	$272	-$221	$51	$51	$272
2013	$277	-$225	$51	$51	$277
2014	$281	-$229	$52	$52	$281
2015	$285	-$263	$23	$23	$285
2016	$290	-$268	$22	$22	$290
2017	$295	-$273	$22	$22	$295
2018	$299	-$278	$22	$22	$299
2019	$304	-$283	$21	$21	$304
2020	$308	-$287	$21	$21	$308
2021	$313	-$292	$21	$21	$313
2022	$318	-$297	$20	$20	$318
2023	$322	-$302	$20	$20	$322
2024	$327	-$307	$20	$20	$327
2025	$332	-$312	$20	$20	$332
2026	$337	-$317	$20	$20	$337
2027	$341	-$322	$19	$19	$341
2028	$346	-$327	$19	$19	$346
2029	$351	-$332	$19	$19	$351
2030	$356	-$337	$19	$19	$356
2031	$361	-$342	$19	$19	$361
2032	$365	-$347	$19	$19	$365
2033	$370	-$352	$18	$18	$370
2034	$375	-$357	$18	$18	$375
2035	$380	-$362	$18	$18	$380
2036	$385	-$367	$18	$18	$385
NPV 2004-2036	**$5,514**	**-$5,009**	**$505**	**$505**	**$5,514**

Note: for fuel costs see Table 8.4-2; for cost allocations by pollutant see Table 8.1-2.

8.5 Summary of Total Aggregate Costs of the Proposed Program

Table 8.5-1 presents a summary of all the costs presented above for the proposed program. Engine costs are the summation of costs presented in Tables 8.2-1 and 8.2-2, equipment costs are the summation of costs presented in Tables 8.3-1 and 8.3-2, and fuel costs and net maintenance costs are presented in Table 8.4-5. The “Total Program Costs” are the summation of engine costs, equipment costs, and net fuel costs. Table 8.5-2 presents the summary of all the costs presented above for the proposed program by pollutant (refer to Table 8.1-2 for how we have allocated costs among the various pollutants). We did the cost analysis using a 3% discount rate. We will also be conducting a similar analysis using a 7% discount rate and including this information in the docket.

Note that the total aggregate costs associated with the 500 ppm fuel program are presented in full in Table 8.4-6 since there are no new engine or equipment costs associated with that program.

Table 8.5-1
Summary of Aggregate Costs for the Proposed Two-Step Fuel and Engine Program by Segment
(millions)

Year	Engine Costs	Equipment Costs	Fuel Costs	Net Maintenance Costs	Net Operating Costs	Total Costs
2004	$0	$0	$0	$0	$0	$0
2005	$0	$0	$0	$0	$0	$0
2006	$0	$0	$0	$0	$0	$0
2007	$0	$0	$136	-$118	$18	$18
2008	$80	$5	$238	-$206	$32	$117
2009	$82	$5	$242	-$210	$31	$118
2010	$79	$5	$345	-$225	$121	$205
2011	$410	$59	$425	-$228	$197	$665
2012	$723	$99	$433	-$218	$215	$1,037
2013	$875	$114	$440	-$204	$236	$1,226
2014	$973	$134	$458	-$197	$260	$1,367
2015	$889	$134	$473	-$219	$254	$1,277
2016	$909	$135	$481	-$210	$271	$1,315
2017	$912	$135	$489	-$201	$288	$1,335
2018	$908	$131	$498	-$194	$304	$1,342
2019	$907	$131	$506	-$188	$318	$1,356
2020	$921	$132	$514	-$182	$332	$1,384
2021	$934	$90	$522	-$178	$344	$1,368
2022	$948	$63	$531	-$175	$356	$1,367
2023	$962	$54	$539	-$172	$367	$1,383
2024	$975	$36	$548	-$169	$378	$1,389
2025	$989	$36	$556	-$168	$389	$1,414
2026	$1,003	$37	$565	-$166	$398	$1,438
2027	$1,016	$37	$573	-$166	$407	$1,461
2028	$1,030	$38	$581	-$166	$416	$1,484
2029	$1,044	$38	$590	-$166	$424	$1,506
2030	$1,058	$39	$598	-$166	$432	$1,528
2031	$1,071	$39	$607	-$167	$440	$1,550
2032	$1,085	$39	$615	-$167	$449	$1,573
2033	$1,099	$40	$624	-$167	$457	$1,596
2034	$1,112	$40	$632	-$167	$466	$1,618
2035	$1,126	$41	$641	-$167	$474	$1,641
2036	$1,140	$41	$650	-$166	$483	$1,664
NPV 2004-2036	$14,215	$1,215	$8,729	($3,445)	$5,284	$20,713

Table 8.5-2
Summary of Aggregate Costs for the Proposed Two-Step Fuel and Engine Program by Pollutant
(millions)

Year	PM Costs	NOx+NMHC Costs	SOx Costs	Total Costs
2004	$0	$0	$0	$0
2005	$0	$0	$0	$0
2006	$0	$0	$0	$0
2007	$0	$0	$18	$18
2008	$85	$0	$31	$117
2009	$86	$0	$31	$118
2010	$111	$27	$68	$205
2011	$400	$172	$93	$665
2012	$664	$279	$94	$1,037
2013	$826	$304	$95	$1,226
2014	$829	$463	$74	$1,367
2015	$761	$457	$59	$1,277
2016	$806	$449	$60	$1,315
2017	$825	$450	$61	$1,335
2018	$825	$456	$61	$1,342
2019	$846	$448	$62	$1,356
2020	$867	$455	$62	$1,384
2021	$865	$440	$63	$1,368
2022	$871	$433	$63	$1,367
2023	$880	$440	$64	$1,383
2024	$888	$437	$65	$1,389
2025	$906	$443	$65	$1,414
2026	$922	$449	$66	$1,438
2027	$939	$456	$67	$1,461
2028	$954	$462	$67	$1,484
2029	$970	$468	$68	$1,506
2030	$985	$475	$69	$1,528
2031	$1,000	$481	$69	$1,550
2032	$1,016	$487	$70	$1,573
2033	$1,032	$493	$71	$1,596
2034	$1,047	$500	$71	$1,618
2035	$1,063	$506	$72	$1,641
2036	$1,079	$512	$73	$1,664
NPV 2004-2036	$13,117	$6,419	$1,177	$20,713

8.6 Emission Reductions

Table 8.6-1 presents the emission reductions estimated to result from the proposed two-step fuel program in conjunction with the proposed engine program. Also presented are reductions associated with the 500 ppm fuel program. A complete discussion of these emission reductions and how they were generated can be found in Chapter 3 of this draft RIA.

Table 8.6-1
Emission Reductions Associated with the Proposed Two-Step Fuel and Engine Program (tons)[a]

Year	Proposed Two-Step Fuel Program and Engine Program			500 ppm Fuel Program
	NOx+NMHC	PM	SOx	SOx[b]
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	0	11,636	144,298	144,298
2008	331	20,911	252,100	252,100
2009	679	21,936	256,935	256,935
2010	1,100	23,976	273,470	261,786
2011	21,527	27,947	287,583	267,117
2012	54,771	34,221	292,817	271,879
2013	92,356	41,592	297,975	276,559
2014	159,869	49,424	303,138	281,244
2015	227,196	57,447	308,386	286,014
2016	293,259	65,327	313,862	291,018
2017	356,969	72,981	319,130	295,815
2018	416,003	80,207	324,374	300,591
2019	471,893	86,972	329,641	305,392
2020	523,758	93,290	334,799	310,086
2021	569,840	99,189	340,233	315,058
2022	611,898	104,709	345,674	320,039
2023	651,009	109,897	351,122	325,028
2024	687,113	114,844	356,578	330,025
2025	721,134	119,594	362,041	335,032
2026	752,239	124,061	367,483	340,021
2027	780,753	128,162	372,933	345,019
2028	807,161	131,868	378,391	350,027
2029	831,947	135,400	383,859	355,045
2030	854,392	138,813	389,337	360,073
2031	875,480	141,991	394,825	365,112
2032	895,923	145,065	400,323	370,162
2033	915,611	148,083	405,832	375,223
2034	934,719	151,025	411,352	380,295
2035	953,145	153,851	416,883	385,378
2036	971,043	156,591	422,425	390,472
NPV 2004-2036	7,909,477	1,501,011	5,977,653	5,585,742

[a] Note that values shown here are emissions reductions. Chapter 3 presents emissions inventories. The values here are the differences between the baseline inventory values and the proposal inventory values presented in Chapter 3.

[b] Note that the SOx reductions for the two-step fuel program and the 500 ppm fuel program are identical during the years 2007 through 2010 because only 500 ppm fuel is available during those years. The introduction of 15 ppm fuel in 2010 under the two-step fuel program results in slightly greater SOx reductions for that program relative to the 500 ppm fuel program.

8.7 Cost per Ton

We have calculated the cost per ton of our proposed program based on the net present value of all costs incurred and all emission reductions generated over a 30 year time window following implementation of the program. This approach captures all of the costs and emissions reductions from our proposed program including those costs incurred and emissions reductions generated by the existing fleet.

The baseline (i.e., the point of comparison) for this evaluation is the existing set of engine standards (i.e., the Tier 2/Tier 3 program) and fuel standards (i.e., unregulated sulfur level). The 30-year time window chosen is meant to capture both the early period of the program when very few new engines that meet the proposed standards would be in the fleet, and the later period when essentially all engines would meet the proposed standards. The proposed program also would require reductions in sulfur content of nonroad diesel fuel (and also locomotive and marine diesel fuel). We are proposing a 500 ppm sulfur cap on nonroad, locomotive, and marine fuels beginning in 2007. This fuel program, the first step in our two-step fuel program, provides significant air quality benefits through reduced SO_x emissions, see Tables 3.5-4 and 3.5-5, and PM emissions, see Tables 3.5-1 and 3.5-2, from both new and existing nonroad, locomotive, and marine engines. In Table 8.4-6 we summarized the cost for this program as if it remained in place for 30 years, even though it would be supplanted by the second step of our fuel program in 2010. In Table 8.6-1, we presented the SO_x emission reductions expected from this program. Here we provide an analysis of the cost per ton for the SO_x reductions that would be realized by the 500 ppm fuel program for the same 30 year time window. In this way, the cost per ton of the SO_x reductions realized by the 500 ppm fuel program can be compared to other available means to control SO_x emissions. The PM reductions are not accounted for in the relative cost per ton estimate, but are listed in Section 3.5.

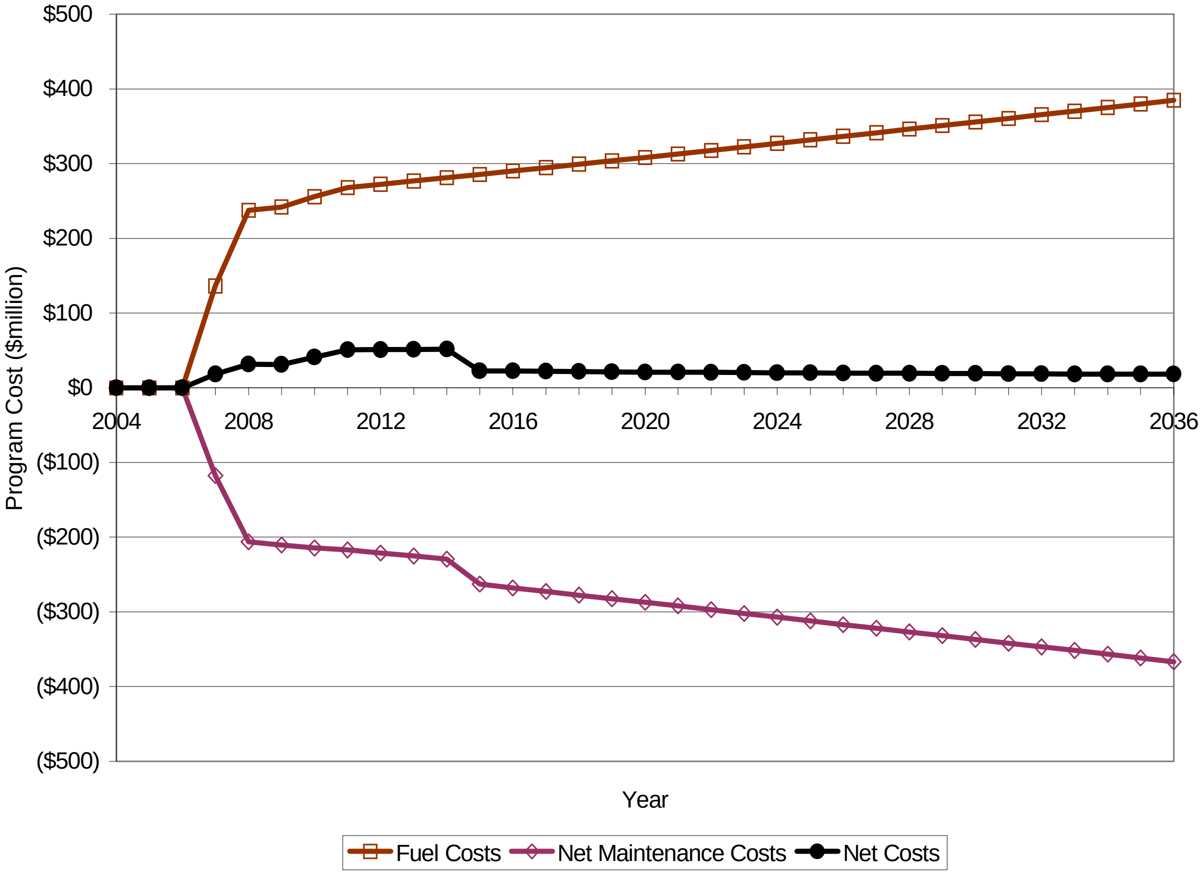
We are also proposing a second step in the fuel program that would cap nonroad fuel sulfur levels at 15 ppm beginning in 2010. This fuel program enables the introduction of advanced emission control technologies including CDPFs and NOx adsorbers. The combination of the two-step fuel program and the new diesel engine standards represents the total Tier 4 program for nonroad diesel engines and fuel proposed today. In Table 8.5-2, we presented our estimate of the annual costs for this complete program by pollutant beginning in 2007 and continuing for 30 years. In Table 8.6-1, we presented the estimated emission reductions for this proposed program. Here we include an estimate of the cost per ton of emissions reductions realized by this program for NOx+NMHC, PM, and SO_x.

8.7.1 Cost per Ton for the 500 ppm Fuel Program

Table 8.4-6 contains the aggregate fuel costs and net maintenance costs for the 500 ppm fuel program from 2007-20036. Cost estimates in Table 8.4-6 differ from those in Table 8.5-1 (which presents total aggregate costs of the two-step fuel program plus the engine program) because the costs of the second fuel step, related engine standards, equipment modifications and associated maintenance costs are not part of the 500 ppm fuel program. Figure 8.7-1 presents the total annual costs associated with the 500 ppm fuel program through 2036; this is a graphical representation of the data presented in Table 8.4-6

As can be seen in Figure 8.7-1, the costs for refining and distributing the 500 ppm fuel range from $250 million in 2008 to nearly $400 million in 2036. These control costs are largely offset by the maintenance savings that range from $200 million in 2008 to $380 million in 2036. As a result, the net cost of the program in each year is essentially zero, ranging from $50 million in the early years to only $18 million in 2036. The net present value of the net costs and savings associated with the proposed 500 ppm fuel program during the years 2007 to 2036 is estimated at $510 million.

Figure 8.7-1
Annual Costs of the 500 ppm Fuel Program



The 500 ppm fuel program would result in significant reductions in SO_x and PM emissions. For the existing fleet, approximately 98 percent of fuel sulfur is converted to SO_x in the engine with the remaining two percent being emitted in the exhaust as sulfate PM. Because the majority of the emissions reductions associated with this program would be SO_x, we have attributed all the control costs to SO_x in calculating the cost per ton for the 500 ppm fuel program. Table 8.6-1 presents the SO_x reductions for the 500 ppm fuel program from 2007-2036 which are shown in the table to have a net present value of 5.6 million tons. The PM reductions for the 500 ppm fuel program are listed in Section 3.5.

Table 8.7-1 shows the cost per ton of emissions reduced as a result of the proposed 500 ppm fuel program. The cost per ton numbers include costs and emission reductions that would occur from both the new and the existing fleet (i.e., those pieces of nonroad equipment that were sold into the market prior to the proposed emission standards) of nonroad, locomotive, and marine engines. The long term cost per ton is actually negative. This occurs because nonroad engines would experience a net savings due to the 500 ppm fuel program (2.4 cents per gallon for the fuel and 3 cents per gallon for maintenance savings) while locomotive and marine engines would experience a net cost (2.4 cents per gallon for the fuel and 1.1 cents per gallon for maintenance savings). Higher growth in nonroad fuel consumption relative to locomotive and marine fuel consumption eventually results in net negative costs of the 500 ppm fuel program (see Table 8.4-3 or Figure 8.7-1).

Table 8.7-1
Aggregate Cost per Ton for the 500 ppm Fuel Program
2004-2036 Net Present Values at 3% Discount Rate ($2001)

Item	Millions (except $/ton values)	Source
500 ppm gallons at $0.025/gal (2007-2010)	25,206	Table 8.4-2
500 ppm gallons at $0.024/gal (2010+)	203,483	Table 8.4-2
Fuel Cost	$5,514	Table 8.4-6
Net Maintenance Cost	-$5,009	Table 8.4-6
SOx Reduction	5,586	Table 8.6-1
Cost per Ton (with Maintenance Savings)	$90	Calculated
Cost per Ton (without Maintenance Savings)	$990	Calculated

8.7.2 Cost per Ton for the Proposed Program

The proposed program contains a two-step fuel program which is a reduction in sulfur levels for nonroad diesel fuel from current uncontrolled levels ultimately to 15 ppm, though we are proposing an interim cap of 500 ppm. Beginning June 1, 2007, refiners would therefore be required to produce nonroad, locomotive, and marine diesel fuel that meets a maximum sulfur level of 500 ppm. Then, beginning in June 1, 2010, fuel used for nonroad diesel applications (excluding locomotive and marine engines) is proposed to meet a maximum sulfur level of 15 ppm, since all 2011 and later model year nonroad diesel-fueled engines with aftertreatment must be refueled with this new low sulfur diesel fuel.

The costs of the proposal include costs associated with both steps in the fuel program and costs for the engine standards including equipment modifications. Maintenance costs and savings realized by both the existing fleet (nonroad, locomotive, and marine) and the new fleet of engines complying with the proposed standards are included. Figure 8.7-2 presents in graphic form the cost of the proposed program. These costs are also summarized in Table 8.5-1. The cost streams include the amortized capital (fixed) costs and variable costs.

Figure 8.7-2
Costs of the Proposed Fuel and Engine Program

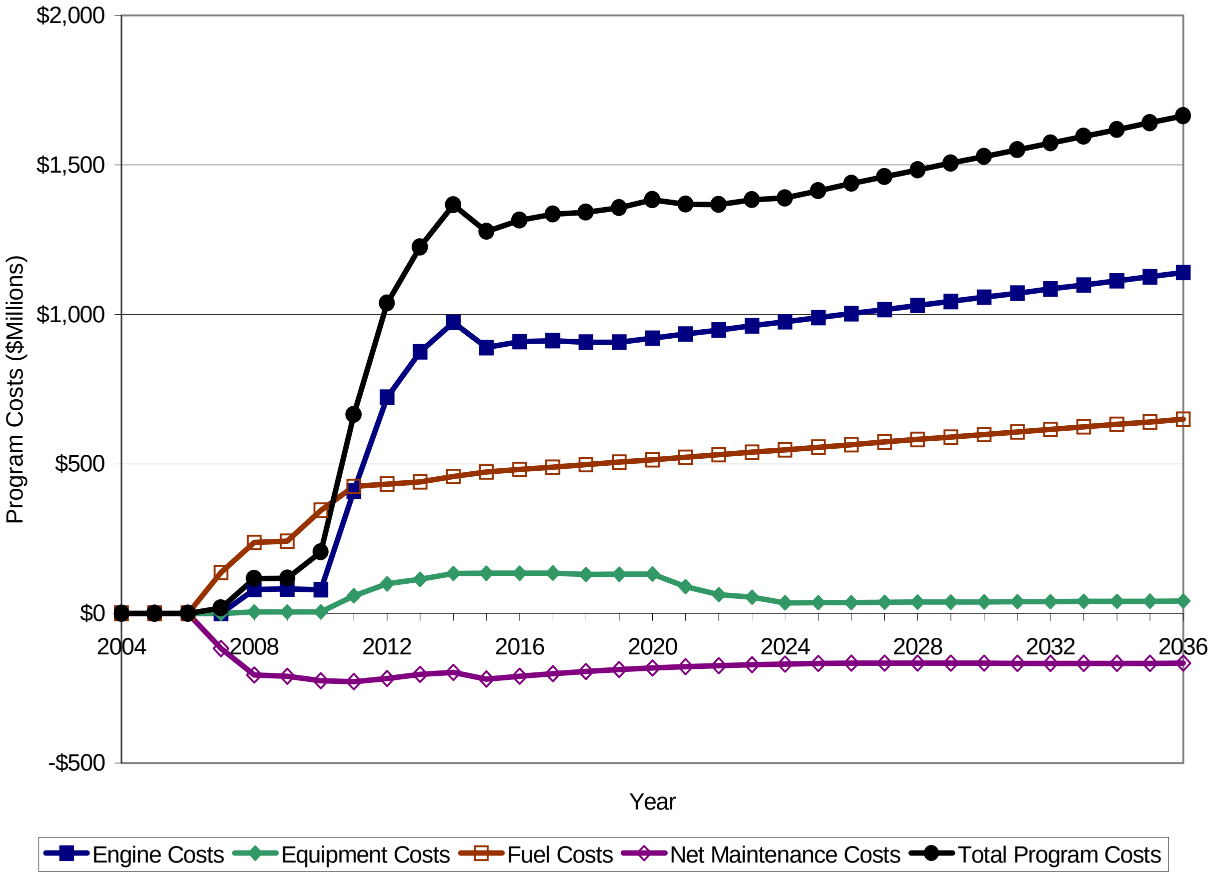


Figure 8.7-2 shows that total annual costs are estimated to be $120 million in the first year the new engine standards apply, increasing to $1.7 billion in 2036 as increasing numbers of engines become subject to the new standards and an ever increasing amount of fuel is consumed. As shown in Table 8.5-1, the net present value of a 30 year window from 2007 to 2036 is $20.7 billion.

The calculations of cost per ton of each emission reduced for the total program divides the net present value of the annual costs assigned to each pollutant (see Table 8.5-2 for costs by pollutant and Table 8.1-2 for how we have allocated costs by pollutant) by the net present value of the total annual reductions of each pollutant – NOx+NMHC, PM and SOx (see Table 8.6-1).

The net present value of the costs associated with each pollutant, calculated with a three percent discount rate, are shown in Table 8.5-1 as $6.4 billion for NOx+NMHC, $13.1 billion for PM and $1.2 billion for SO_x. The 30 year net present value, with a three percent discount rate, of emission reductions are 7.9 million tons for NOx+NMHC, 1.5 million tons for PM and 6.0 million tons for SO_x. Our air quality analysis and benefits analysis are found in Chapter 3 and Chapter 9, respectively.

The cost per ton of emissions reduced associated with the proposed engine and fuel program are calculated by dividing the net present value of the annualized costs of the program through 2036 by the net present value of the annual emission reductions through 2036. These results are shown in Table 8.7-2.

Table 8.7-2
Aggregate Cost per Ton for the Proposed Two-Step Fuel Program and Engine Program
2004-2036 Net Present Values at 3% Discount Rate ($2001)

Item	Millions (except $/ton values)	Source
500 ppm gallons at $0.025/gal (2007-2010)	25,206	Table 8.4-1
500 ppm gallons at $0.026/gal (2010-2014)	16,077	Table 8.4-1
500 ppm gallons at $0.024/gal (2014+)	54,791	Table 8.4-1
15 ppm gallons at $0.048/gal (2010-2014)	19,763	Table 8.4-1
15 ppm gallons at $0.048/gal (2014+)	112,851	Table 8.4-1
500 ppm Fuel Cost	$2,363	Table 8.4-5
15 ppm Fuel Cost	$6,366	Table 8.4-5
Net Maintenance Cost	-$3,445	Table 8.4-5
Engine Costs	$14,215	Table 8.5-1
Equipment Costs	$1,215	Table 8.5-1
Total Program Costs	$20,713	Table 8.5-1
NOx+NMHC Costs	$6,419	Table 8.5-2
PM Costs	$13,117	Table 8.5-2
SOx Costs	$1,177	Table 8.5-2
NOx+NMHC Reduction	7,909	Table 8.6-1
PM Reduction	1,501	Table 8.6-1
SOx Reduction	5,978	Table 8.6-1
Cost per Ton NOx+NMHC	$810	Calculated
Cost per Ton PM	$8,700	Calculated
Cost per Ton SOx	$200*	Calculated

* This result does not match that in Table 8.4-2 because the nonroad portion of the fuel is reduced to 15 ppm and does not stay at 500 (locomotive and marine portions are kept at 500ppm). The costs to reduce fuel sulfur from uncontrolled levels to 15ppm were assigned 50/50 to NOx+NMHC and PM because the reduction to 15 ppm is to enable aftertreatment technology.

We have also calculated the cost per ton of emissions in the year 2036 using the annual costs and emission reductions in that year alone. This number, shown in Table 8.7-3, approaches the long term cost per ton of emissions reduced after all fixed costs of the program have been recovered by industry leaving only the variable costs of control (and maintenance costs), and after most (though not all) of the pre-control fleet has been retired.

Table 8.7-3
Long Term Cost per Ton of the Proposed Two-Step Fuel Program and Engine Program
Annual Values without Discounting ($2001)

Pollutant	Long-Term Cost per Ton in 2036
NOx+NMHC	$530
PM	$6,900
SO_x	$170

Chapter 8 References

1. Power Systems Research, OELink Sales Version, 2002.

2. Nonroad Engine Growth Estimate, Report No. NR-008b, Docket Item II-A-32.

3. “Engine Sales Used in Proposed Nonroad Tier 4 Cost Analysis,” memorandum from Todd Sherwood to Public Docket No. A-2001-28.

CHAPTER 9: Cost-Benefit Analysis

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CHAPTER 9: Cost-Benefit Analysis

This chapter reports EPA's analysis of the public health and welfare impacts and associated monetized benefits to society of the proposed Nonroad Diesel Engines Tier 4 Standards. EPA is required by Executive Order 12866 to estimate the costs and benefits of major new pollution control regulations. Accordingly, the analysis presented here attempts to answer three questions: 1) what are the physical health and welfare effects of changes in ambient air quality resulting from reductions in nitrogen oxides (NOx), sulfur dioxide (SO_2), non-methane hydrocarbons (NMHC), carbon monoxide (CO) and direct diesel particulate matter ($PM_{2.5}$)[A] emissions?; 2) how much are the changes in these effects attributable to the proposed rule worth to U.S. citizens as a whole in monetary terms?; and 3) how do the monetized benefits compare to the costs over time? It constitutes one part of EPA's thorough examination of the relative merits of this proposed regulation. In Chapter 12, we provide an analysis of the benefits of several alternatives to the proposed standards to examine their relative benefits and costs.

Due to the time requirements for running the sophisticated emissions and air quality models needed to obtain estimates of the changes in air quality expected to result from implementation of emission controls, it is often necessary to select a set of preliminary control options for the purposes of emissions and air quality modeling. The standards we are proposing in this rulemaking are slightly different in the amount of emission reductions expected to be achieved in 2020 and 2030 relative to the preliminary control options that we modeled. EPA has used the best available information and tools of analysis to quantify the expected changes in public health, environmental and economic benefits of the preliminary control options. We summarize the results of that analysis in section 9.3, and present details in Appendix 9A, directly following this chapter. However, we determined that additional analysis was necessary to reflect the differences in emission reductions between the modeled and proposed standards. The results of that additional analysis are the focus of this chapter.

In order to characterize the benefits attributable to the proposed Nonroad Diesel Engines standards, given the constraints on time and resources available for the analysis, we use a benefits transfer method to scale the benefits of the modeled preliminary control options to reflect the differences in emission reductions. We also apply intertemporal scaling factors to examine the stream of benefits over the rule implementation period. The benefits transfer method used to estimate benefits for the proposed standards is similar to that used to estimate benefits in the recent analysis of the Large SI/Recreational Vehicles standards (see RIA, Docket A-2000-01). A similar method has also been used in recent benefits analyses for the proposed Industrial Boilers and Process Heaters MACT standards and the Reciprocating Internal Combustion Engines MACT standards. One significant limitation to this method is the inability

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[A] Emissions from nonroad diesel engines include directly emitted particles as well as gaseous pollutants that react in the atmosphere to form fine particles. This proposed rule will results in reductions in ambient PM particle levels due to reductions in both directly emitted particles as well as reductions in PM precursor emissions, including NOx and SO_2.

to scale ozone-related benefits. Because ozone is a homogeneous gaseous pollutant formed through complex atmospheric photochemical processes, it is not possible to apportion ozone benefits to the precursor emissions of NOx and VOC. Coupled with the potential for NOx reductions to either increase or decrease ambient ozone levels, this prevents us from scaling the benefits associated with a particular combination of VOC and NOx emissions reductions to another (a more detailed discussion is provided below). Because of our inability to scale ozone benefits, we provide the ozone benefits results for the modeled preliminary control options as a referent, but do not include ozone benefits as part of the monetized benefits of the proposed standards. For the most part, quantifiable ozone benefits do not contribute significantly to the monetized benefits: thus, their omission will not materially affect the conclusions of the benefits analysis.

Table 9-1 lists the known quantifiable and unquantifiable effects considered for this analysis. Note that this table categorizes ozone-related benefits as unquantified effects. We have quantified ozone-related benefits in our analysis of a set of preliminary benefits, summarized in Section 9.3 and detailed in Appendix 9A. However, as noted above, we are unable to quantify ozone-related benefits for the rule we are proposing. It is important to note that there are significant categories of benefits which can not be monetized (or in many cases even quantified), resulting in a significant limitation to this analysis. Also, EPA currently does not have appropriate tools for modeling changes in ambient concentrations of CO or air toxics input into a national benefits analysis. Although these pollutants have been linked to numerous adverse health effects, we are unable to quantify the CO- or air toxics-related health or welfare benefits of the proposed rule at this time.

The benefit analysis that we performed for our proposed rule can be thought of as having seven parts, each of which will be discussed separately in the Sections that follow. These seven steps are:

1. Identification of proposed standards and calculation of the impact that the proposed standards will have on the nationwide inventories for NOx, non-methane hydrocarbons (NMHC), SO_2, and PM emissions throughout the rule implementation period;
2. Calculation of scaling factors relating emissions changes resulting from the proposed standards to emissions changes from a set of preliminary control options that were used to model air quality and benefits (see Appendix 9A for full details).
3. Apportionment of modeled benefits of preliminary control options to NOx, SO_2, and diesel PM emissions (see Appendix 9A for a complete discussion of the modeling of the benefits for the preliminary set of standards).
4. Application of scaling factors to apportioned modeled benefits associated with NOx, SO_2, and PM in 2020 and 2030.
5. Development of intertemporal scaling factors based on 2020 and 2030 modeled air quality and benefits results.

6. Application of intertemporal scaling factors to the yearly emission changes expected to result from the proposed standards from 2010 through 2030 to obtain yearly monetized benefits.
7. Calculation of present value of stream of benefits.

This primary analysis presents estimates of the potential benefits from the proposed Nonroad Diesel Engine rule occurring in future years. The predicted emissions reductions that will result from the rule have yet to occur, and therefore the actual changes in human health and welfare outcomes to which economic values are ascribed are predictions. These predictions are based on the best available scientific evidence and judgment, but there is unavoidable uncertainty associated with each step in the complex process between regulation and specific health and welfare outcomes. Uncertainties associated with projecting input and parameter values into the future may contribute significantly to the overall uncertainty in the benefits estimates. However, we make these projections to more completely examine the impact of the program as the equipment fleet turns over.

In addition, we have also evaluated an alternative, more conservative estimate that can provide useful insight into the potential impacts of the key elements underlying estimates of the benefits of reducing NOx and PM emissions from this rule through calculated alternative benefits for mortality and chronic bronchitis. The alternative approach uses different data on valuation and makes adjustments relating to the health status and potential longevity of the populations most likely affected by PM. We are continuing to examine the merits of applying this alternative approach to the calculation of benefits. Some of the issues that warrant further investigation are described later in this chapter.

In general, the chapter is organized around the steps laid out above. In section 1, we identify the potential standard to analyze, establish the timeframe over which benefits are estimated, and summarize emissions impacts. In section 2, we summarize the changes in emissions that were used in the preliminary modeled benefits analysis and develop ratios of proposed to preliminary emissions that are used to scale modeled benefits. In section 3, we summarize the modeled benefits associated with the emissions changes for the preliminary control options and apportion those benefits to the individual emission species (NOx, SO_2, and $PM_{2.5}$). In Section 4, we estimate the benefits in 2020 and 2030 for the proposed standards, based on scaling of the modeled benefits of the preliminary control options. In section 5, we develop intertermporal scaling factors based on the ratios of yearly emission changes to the emission changes in 2020 and 2030 and estimate yearly benefits of the proposed standards, based on scaling of the benefits in 2020 and 2030. Finally, in Section 6, we compare the estimated streams of benefits and costs over the full implementation period, 2007 to 2030, to calculate the present value of net benefits for the proposed standards.

Table 9-1
Health and Welfare Effects of Pollutants Affected by the Proposed Nonroad Diesel Engine Rule

Pollutant/Effect	Quantified and Monetized in Base and Alternative Estimates	Quantified and/or Monetized Effects in Sensitivity Analyses	Unquantified Effects
PM/Health	Premature mortality – long term exposures Premature mortality – short term exposures Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Non-fatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted activity days Work loss days	Asthma attacks (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits Changes in cardiac function (e.g. heart rate variability) Allergic responses (to diesel exhaust)
PM/Welfare	Visibility in California, Southwestern, and Southeastern Class I areas	Visibility in Northeastern, Northwestern, and Midwestern Class I areas Visibility in residential and non-Class I areas Household soiling	

Pollutant/Effect	Quantified and Monetized in Base and Alternative Estimates	Quantified and/or Monetized Effects in Sensitivity Analyses	Unquantified Effects
Ozone/Health			Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection Non-asthma respiratory emergency room visits Hospital admissions - respiratory Emergency room visits for asthma Minor restricted activity days School loss days Chronic Asthma[a] Asthma attacks Cardiovascular emergency room visits Premature mortality – acute exposures[b] Acute respiratory symptoms
Ozone/Welfare			Decreased commercial forest productivity Decreased yields for fruits and vegetables Decreased yields for commercial and non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Damage to ecosystem functions Decreased outdoor worker productivity
Nitrogen and Sulfate Deposition/ Welfare		Costs of nitrogen controls to reduce eutrophication in selected eastern estuaries	Impacts of acidic sulfate and nitrate deposition on commercial forests Impacts of acidic deposition on commercial freshwater fishing Impacts of acidic deposition on recreation in terrestrial ecosystems Impacts of nitrogen deposition on commercial fishing, agriculture, and forests Impacts of nitrogen deposition on recreation in estuarine ecosystems Reduced existence values for currently healthy ecosystems
SO_2/Health			Hospital admissions for respiratory and cardiac diseases Respiratory symptoms in asthmatics

Pollutant/Effect	Quantified and Monetized in Base and Alternative Estimates	Quantified and/or Monetized Effects in Sensitivity Analyses	Unquantified Effects
NOx/Health			Lung irritation Lowered resistance to respiratory infection Hospital Admissions for respiratory and cardiac diseases
CO/Health			Premature mortality Behavioral effects Hospital admissions - respiratory, cardiovascular, and other Other cardiovascular effects Developmental effects Decreased time to onset of angina
NMHCs [c] Health			Cancer (diesel PM, benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucous membranes (formaldehyde) Respiratory and respiratory tract Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation & congestion (acrolein)
NMHCs [c] Welfare			Direct toxic effects to animals Bioaccumlation in the food chain Reduced odors

[a] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, two epidemiological studies shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in exercising children and some non-smoking men (McConnell, 2002; McDonnell, et al., 1999).

[b] Premature mortality associated with ozone is not separately included in the calculation of total monetized benefits.

[c] All non-methane hydrocarbons (NMHCs) listed in the table are also hazardous air pollutants listed in Section 112(b) of the Clean Air Act.

9.1 Time Path of Emission Changes for the Proposed Standards

The proposed standards have various cost and emission related components, as described earlier in this RIA. These components would begin at various times and in some cases would phase in over time. This means that during the early years of the program there would not be a consistent match between cost and benefits. This is especially true for the equipment control portions and initial fuel changes required by the program, where the full equipment cost would be incurred at the time of equipment purchase, while the fuel and maintenance costs, along with the emission reductions and benefits resulting from all these costs would occur throughout the lifetime of the equipment. Because of this inconsistency and our desire to more appropriately match the costs and emission reductions of our program, our analysis examines costs and benefits throughout the period of program implementation. This chapter focuses on estimating the stream of benefits over time and comparing streams of benefits and costs. Detailed information on cost estimates can be found in chapters 6, 7 and 8 of this RIA.

For the proposed standards, implementation will occur in two stages: reduction in sulfur content of nonroad diesel fuel and adoption of controls on most new nonroad engines. Because full turnover of the fleet of nonroad diesel engines will not occur for many years, the emission reduction benefits of the proposed standards will not be fully realized until several decades after the reduction in fuel sulfur content. The timeframe for the analysis reflects this turnover, beginning in 2010 and extends through 2030.

Chapter 3 discussed the development of the 1996, 2020 and 2030 baseline emissions inventories for the nonroad sector and for the sectors not affected by this proposed rule. The emission sources and the basis for current and future-year inventories are listed in Table 9-2. Using these modeled inventories, emissions with and without the proposed regulations are interpolated to provide streams of emissions from the rule implementation date through full implementation in 2030. These streams of emissions are presented in Chapter 3 and summarized in Table 9-3 for the species that form the inputs to the benefits modeling. NOx and VOC contribute to ambient ozone formation, while NOx, SO_2, NMHC/VOC, and directly emitted $PM_{2.5}$ emissions are precursors to ambient $PM_{2.5}$ and PM_{10} concentrations. Although the rule is expected to reduced CO and air toxics emissions as well, we do not include benefits related to these reductions in the benefits analysis due to a lack of appropriate air quality and exposure models.

Table 9-2
Emissions Sources and Basis for Current and Future-Year Inventories

Emissions Source	1996 Base year	Future-year Base Case Projections
Utilities	1996 NEI Version 3.12 (CEM data)	Integrated Planning Model (IPM)
Non-Utility Point and Area sources	1996 NEI Version 3.12 (point) Version 3.11 (area)	BEA growth projections
Highway vehicles	MOBILE5b model with MOBILE6 adjustment factors for VOC and NOx; PART5 model for PM	VMT projection data
Nonroad engines (except locomotives, commercial marine vessels, and aircraft)	NONROAD2002 model	BEA and Nonroad equipment growth projections

Note: Full description of data, models, and methods applied for emissions inventory development and modeling are provided in the Emissions Inventory TSD (U.S. EPA, 2003a).

Table 9-3.
Summary of 48-State Baseline Emissions for
Nonroad Diesel Engines for Key Emission Species[a]

	Annual Tons			
	NOx	SO_2	VOC	PM2.5
2000	1,591,801	243,333	191,136	218,311
2005	1,509,081	273,331	155,943	194,554
2010	1,319,917	288,617	122,996	179,213
2015	1,199,235	315,367	101,641	178,559
2020	1,175,544	341,941	93,241	183,250
2025	1,211,002	369,475	91,709	191,976
2030	1,273,245	397,109	93,899	201,567

[a] Excludes Alaska and Hawaii.

Table 9-4 summarizes the expected changes in emissions of key species. SO_2 emissions are expected to be reduced by over 90 percent within the first two years of implementation. Emissions of NOx, NMHC, and $PM_{2.5}$ are expected to be reduced gradually over the period of implementation from 2007 to 2030. Overall, NOx, SO_2, NMHC, and $PM_{2.5}$ emissions are expected to decline by 65, 97, 30, and 63 percent, respectively, over the 2007 to 2030 implementation period.

Table 9-4
Summary of Reduction in 48-State Emissions
Attributable to Proposed Nonroad Diesel Engine Standards

	Tons Reduced (% of baseline)			
	NOx	SO_2	VOC	$PM_{2.5}$
2010	1,007	270,977	90	21,864
	0.2%	93.9%	0.4%	11.8%
2015	217,575	305,639	8,788	52,476
	18.1%	96.9%	8.5%	28.7%
2020	503,701	331,840	18,033	85,254
	42.8%	97.0%	18.6%	46.0%
2025	693,857	358,863	24,624	109,325
	57.2%	97.1%	25.6%	56.6%
2030	821,911	385,932	29,487	126,910
	64.5%	97.2%	29.9%	62.8%

9.2 Development of Benefits Scaling Factors Based on Differences in Emission Impacts Between Proposed and Modeled Preliminary Control Options

Based on the projected time paths for emissions reductions, we focused our detailed emissions and air quality modeling on two future years, 2020 and 2030, which reflect partial and close to complete turnover of the fleet of nonroad diesel engines to rule compliant models. The emissions changes modeled for these two years are similar to those in the proposed standards, differing in the treatment of smaller engines and fuel requirements[B]. Table 9-5 summarizes the reductions in emissions of NOx, SO_2, and $PM_{2.5}$ from baseline for the preliminary and proposed standards, the difference between the two, and the ratio of emissions reductions from the proposed standards to the preliminary control options. The ratios presented in the last column of Table 9-5 are the basis for the benefits scaling approach discussed below.

Table 9-5
Comparison of 48-state Emission Reductions
in 2020 and 2030 Between Preliminary and Proposed Standards

Emissions Species	Reduction from Baseline		Difference in Reductions (Proposed-Preliminary)	Ratio of Reductions (Proposed/ Preliminary)
	Preliminary	Proposed		
2020				
NOx	663,618	503,701	-159,917	0.759
SO_2	414,692	331,840	-82,852	0.800
PM2.5	98,121	85,254	-12,867	0.869
2030				
NOx	1,009,744	821,911	-187,833	0.814
SO_2	483,401	385,932	-97,469	0.798
PM2.5	138,208	126,910	-11,298	0.918

9.3 Summary of Modeled Benefits and Apportionment Method

Based on the emissions inventories developed for the preliminary control option, we conducted a benefits analysis to determine the air quality and associated human health and welfare benefits resulting from the reductions in emissions of NOx, SO_2, NMHC/VOC, and PM2.5. Based on the availability of air quality and exposure models, this summary focuses on reporting the health and welfare benefits of reductions in ambient particulate matter (PM) and ozone concentrations. However, health improvements may also come from reductions in exposure to CO and air toxics. The full analysis is available in Appendix 9A and the benefits Technical Support Document (TSD) (Abt Associates, 2003).

[B] Emissions and air quality modeling decisions are made early in EPA's analytical process. Since the preliminary control scenario was developed, EPA has gathered more information regarding the technical feasibility of the standards, and has revised the control scenario. For the reasons discussed in the preamble, EPA has decided not to propose standards based on aftertreatment for certain of the smallest engine sizes. Section 3.6 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary baseline and control scenarios used for the air quality modeling and the proposed baseline and control scenarios.

The reductions in emissions of NOx, SO_2, and $PM_{2.5}$ from nonroad engines in the United States are expected to result in wide-spread overall reductions in ambient concentrations of ozone and $PM_{2.5}$[C]. These improvements in air quality are expected to result in substantial health benefits, based on the body of epidemiological evidence linking PM and ozone with health effects such as premature mortality, chronic lung disease, hospital admissions, and acute respiratory symptoms. Based on modeled changes in ambient concentrations of $PM_{2.5}$ and ozone, we estimate changes in the incidence of each health effect using concentration-response (C-R) functions derived from the epidemiological literature with appropriate baseline populations and incidence rates. We then apply estimates of the dollar value of each health effect to obtain a monetary estimate of the total PM- and ozone-related health benefits of the rule. Welfare effects are estimated using economic models which link changes in physical damages (e.g., light extinction or agricultural yields) with economic values.

9.3.1 Overview of Analytical Approach

This section summarizes the three steps involved in our analysis of the modeled preliminary control options: 1) Calculation of the impact that a set of preliminary fuel and engine standards would have on the nationwide inventories for NOx, NMHC, SO_2, and PM emissions in 2020 and 2030; 2) Air quality modeling for 2020 and 2030 to determine changes in ambient concentrations of ozone and particulate matter, reflecting baseline and post-control emissions inventories; and 3) A benefits analysis to determine the changes in human health and welfare, both in terms of physical effects and monetary value, that result from the projected changes in ambient concentrations of various pollutants for the modeled standards.

We follow a “damage-function” approach in calculating total benefits of the modeled changes in environmental quality. This approach estimates changes in individual health and welfare endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the individual values. Total benefits are calculated simply as the sum of the values for all non-overlapping health and welfare endpoints. This imposes no overall preference structure, and does not account for potential income or substitution effects, i.e. adding a new endpoint will not reduce the value of changes in other endpoints. The “damage-function” approach is the standard approach for most cost-benefit analyses of regulations affecting environmental quality, and it has been used in several recent published analyses (Banzhaf et al., 2002; Levy et al, 2001; Kunzli et al, 2000; Levy et al, 1999; Ostro and Chestnut, 1998). Time and resource constraints prevented us from performing extensive new research to measure either the health outcomes or their values for this analysis. Thus, similar to these studies, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary research from similar

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[C] Reductions in NOx are expected to result in some localized increases in ozone concentrations, especially in NOx-limited large urban areas, such as Los Angeles, New York, and Chicago. A fuller discussion of this phenomenon is provided in Chapter 2.3. While localized increases in ozone will result in some increases in health impacts from ozone exposure in these areas, on net, the reductions in NOx are expected to reduce national levels of health impacts associated with ozone.

contexts to obtain the most accurate measure of benefits available for the environmental quality change under analysis.

There are significant categories of benefits that cannot be monetized (or in many cases even quantified), and thus they are not included in our accounting of health and welfare benefits. These unquantified effects include infant mortality, low birth weight, changes in pulmonary function, chronic respiratory diseases other than chronic bronchitis, morphological changes, altered host defense mechanisms, non-fatal cancers, and non-asthma respiratory emergency room visits. A complete discussion of PM related health effects can be found in the PM Criteria Document (U.S. EPA, 1996). Since many health effects overlap, such as minor restricted activity days and asthma symptoms, we made assumptions intended to reduce the chances of "double-counting" health benefits, which may result in an underestimate of the total health benefits of the pollution controls.

9.3.2 Air Quality Modeling

We used a national-scale version of the REgional Modeling System for Aerosols and Deposition (REMSAD version 7) to estimate PM air quality in the contiguous United States. We used the Comprehensive Air Quality Model with Extensions (CAMx) to estimate ambient ozone concentrations[D], using two domains representing the Eastern and Western U.S. These models are discussed in the air quality TSD for this rule.

9.3.2.1 PM Air Quality Modeling with REMSAD

REMSAD is appropriate for evaluating the impacts of emissions reductions from nonroad sources, because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions. The annual county level emission inventory data described in Chapter 3 was speciated, temporally allocated and gridded to the REMSAD modeling domain to simulate PM concentrations for the 1996 base year and the 2020 and 2030 base and control scenarios. Peer-reviewed for the EPA, REMSAD is a three-dimensional grid-based Eulerian air quality model designed to estimate annual particulate concentrations and deposition over large spatial scales (Seigneur et al., 1999). Each of the future scenarios was simulated using 1996 meteorological data to provide daily averages and annual mean PM concentrations required for input to the concentration-response functions of the benefits analysis. Details regarding the application of REMSAD Version 7 for this analysis are provided in the Air Quality Modeling TSD (U.S. EPA, 2003b). This version reflects updates in the following areas to improve performance and address comments from the 1999 peer-review:

[D] In the benefits analysis of the recent Heavy Duty Engine/Diesel Fuel rule, we used the Urban Airshed Model Variable-Grid (UAM-V) to estimate ozone concentrations in the Eastern U.S. CAMx has a number of improvements relative to UAM and has improved model performance in the Western U.S. Details on the performance of CAMx can be found in Chapter 2 as well as the Air Quality Modeling TSD (U.S. EPA, 2003b).

1. Gas phase chemistry updates to “micro-CB4" mechanism including new treatment for the NO3 and N2O5 species and the addition of several reactions to better account for the wide ranges in temperature, pressure, and concentrations that are encountered for regional and national applications.

2. PM chemistry updates to calculate particulate nitrate concentrations through use of the MARS-A equilibrium algorithm and internal calculation of secondary organic aerosols from both biogenic (terpene) and anthropogenic (estimated aromatic) VOC emissions.

3. Aqueous phase chemistry updates to incorporate the oxidation of SO_2 by O3 and O2 and to include the cloud and rain liquid water content from MM5 meteorological data directly in sulfate production and deposition calculations.

As discussed earlier in Chapter 2, the model tends to underestimate observed $PM_{2.5}$ concentrations nationwide, especially over the western U.S.

9.3.2.2 Ozone Air Quality Modeling with CAMx

We use the emissions inputs described in Chapter 3 with a regional-scale version of CAMx to estimate ozone air quality in the Eastern and Western U.S. CAMx is an Eulerian three-dimensional photochemical grid air quality model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect ozone formation. Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the CAMx is useful for evaluating the impacts of the proposed rule on U.S. ozone concentrations. As discussed earlier in Chapter 2, although the model tends to underestimate observed ozone, especially over the western U.S., it exhibits less bias and error than any past regional ozone modeling application conducted by EPA (i.e., OTAG, On-highway Tier-2, and HD Engine/Diesel Fuel).

Our analysis applies the modeling system separately to the Eastern and Western U.S. for five emissions scenarios: a 1996 baseline projection, a 2020 baseline projection and a 2020 projection with nonroad controls, a 2030 baseline projection and a 2030 projection with nonroad controls. As discussed in detail in the technical support document, a 1996 base year assessment is necessary because the relative model predictions are used with ambient air quality observations from 1996 to determine the expected changes in 2020 and 2030 ozone concentrations due to the modeled emission changes (Abt Associates, 2003). These results are used solely in the benefits analysis.

As discussed in more detail in Chapter 2.3, our ozone air quality modeling showed that the NOx emissions reductions from the preliminary modeled standards are projected to result in increases in ozone concentrations for certain hours during the year, especially in urban, NOx-limited areas. Most of these increases are expected to occur during hours where ozone levels are low (and often below the one-hour ozone standard). However, most of the country experiences decreases in ozone concentrations for most hours in the year.

9.3.3 Health Effect Concentration-Response Functions

Health benefits for this analysis are based on health effect incidence changes due to predicted air quality changes in the years 2020 and 2030. Integral to the estimation of such benefits is a reasonable estimate of future population projections. The underlying data used to create county-level 2020 and 2030 population projections is based on county level allocations of national population projections from the U.S. Census Bureau (Hollman, Mulder and Kallan, 2000). County-level allocations of populations by age, race, and sex are based on economic forecasting models developed by Woods and Poole, Inc, which account for patterns of economic growth and migration. Growth factors are calculated using the Woods and Poole data and are applied to 2000 U.S. Census data.

Fundamental to the estimation of health benefits was our utilization of the PM and ozone epidemiology literature. We rely upon C-R functions derived from published epidemiological studies that relate health effects to ambient concentrations of PM and ozone. The specific studies from which C-R functions are drawn are listed in Table 9-5. While a broad range of serious health effects have been associated with exposure to elevated PM and ozone levels, we include only a subset of health effects in this benefit analysis due to limitations in available C-R functions and concerns about double-counting of overlapping effects (U.S. EPA, 1996). Since the analysis of the Heavy Duty Engine rulemaking, we have added a number of new endpoints, which are described in detail in Appendix 9B.

To generate health outcomes, projected changes in ambient PM and ozone concentrations were put into the Criteria Air Pollutant Modeling System (CAPMS), a customized GIS-based program. CAPMS aggregates population to air quality model grids and calculates changes in air pollution metrics (e.g., daily averages) for input into C-R functions. CAPMS uses grid cell level population data and changes in pollutant concentrations to estimate changes in health outcomes for each grid cell. Details on the application of CAPMS for this analysis are provided in a separate report (Abt Associates, 2003).

The baseline incidences for health outcomes used in our analyses are selected and adapted to match the specific populations studied. For example, we use age- and county-specific baseline total mortality rates in the estimation of PM-related premature mortality. County-level incidence rates are not available for other endpoints. We used national incidence rates whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Sources of baseline incidence rates are reported in Table 9-6.

In this assessment we made analytical judgements affecting both the selection of C-R functions and the application of those functions in estimating impacts on health outcomes. In general, we selected C-R functions that 1) most closely match the pollutants of interest, i.e. PM2.5 and ozone, 2) cover the broadest potentially exposed population (i.e. all ages functions would be preferred to adults 27 to 35), 3) have appropriate model specification (e.g. control for confounding pollutants), 4) have been peer-reviewed, and 5) are biologically plausible. Other factors may also affect our selection of C-R functions for specific endpoints, such as premature mortality. Some of the more important of these relating to premature mortality and chronic illness are discussed below, and are discussed in detail in Appendix 9A. Alternative assumptions about these judgements may lead to substantially different results and they are explored using appropriate sensitivity analyses provided in Appendix 9B.

While there is a consistent body of evidence supporting a relationship between a number of adverse health effects and PM and ozone exposure, there is often only a single study of a specific endpoint covering a specific age group. There may be multiple estimates examining subgroups (i.e. asthmatic children). However, for the purposes of assessing national population level benefits, we chose the most broadly applicable C-R function to more completely capture health benefits in the general population. Estimates for subpopulations are provided in Appendix 9A.

Based on a review of the recent literature on health effects of PM exposure (Daniels et al., 2000; Pope et al, 2002; Rossi et al., 1999; Schwartz, 2000), we chose for the purposes of this analysis to assume that PM-related health effects occur down to natural background (i.e. there is no health effects threshold). We assume that all of the C-R functions are continuous and differentiable down to natural background levels. In addition, we explore this important assumption in a sensitivity analysis described in Appendix 9B.

Premature Mortality

As in the Kunzli et al. (2000) analysis, we focus on the prospective cohort long-term exposure studies in deriving the C-R function for our base estimate of premature mortality. Cohort analyses are better able to capture the full public health impact of exposure to air pollution over time (Kunzli, 2001; NRC, 2002). We selected a C-R function from the re-analysis of the American Cancer Society (ACS) study conducted for the Health Effects Institute (Pope et al., 1995; Krewski et al; 2000)[E]. This C-R function relates annual mean $PM_{2.5}$ levels and all-cause mortality in adults 30 and older. The selected C-R function relates premature mortality and mean $PM_{2.5}$ levels rather than median levels as used in the original ACS analysis. For policy analysis purposes, functions based on the mean air quality levels may be preferable to functions based on the median air quality levels because changes in the mean more accurately reflect the changes in peak values targeted by many policies than do changes in the median.

[E] A recent analysis (Pope et al, 2002) reexamines the ACS cohort using a longer follow-up period. We have examined how using alternative C-R functions derived from this new study impact our results in a sensitivity analysis presented in Appendix 9B.

To reflect concerns about the inherent limitations in the number of studies supporting a causal association between long-term exposure and mortality, an Alternative benefit estimate for premature mortality was derived from the large number of time-series studies that have established a likely causal relationship between short-term measures of PM and daily mortality statistics. The Alternative Estimate assumes that there is no mortality effect of chronic exposures to fine particles. Instead, it assumes that the full impact of fine particles on premature mortality can be captured using a concentration-response function relating daily mortality to short-term fine particle levels. This will clearly provide a lower bound to the mortality impacts of fine particle exposure, as it omits any additional mortality impacts from longer term exposures. Specifically, concentration- response functions based on Schwartz et al. (1996) are employed, with an adjustment to account for recent evidence that daily mortality is associated with particle levels from a number of previous days (Schwartz, 2000). The size of the effect estimates from these models suggests consistency between the findings of studies that examine assocations premature mortality impacts of short-term and long-term exposures. Additional research may be necessary to confirm this trend. Two C-R functions are used for the alternative estimate, one relating short-term $PM_{2.5}$ levels to daily COPD mortality for all ages, and one relating short-term $PM_{2.5}$ levels to non-COPD mortality for all ages.

Chronic Illness

Although there are several studies examining the relationship between PM of different size fractions and incidence of chronic bronchitis, we use a study by Abbey et al (1995) to obtain our estimate of avoided incidences of chronic bronchitis in adults aged 25 and older, because Abbey et al (1995) is the only available estimate of the relationship between $PM_{2.5}$ and chronic bronchitis. Based on the Abbey et al study, we estimate the number of new chronic bronchitis cases that will “reverse” over time and subtract these reversals from the estimate of avoided chronic bronchitis incidences. Reversals refer to those cases of chronic bronchitis that were reported at the start of the Abbey et al. survey, but were subsequently not reported at the end of the survey. Since we assume that chronic bronchitis is a permanent condition, we subtract these reversals. Given the relatively high value assigned to chronic bronchitis, this ensures that we do not overstate the economic value of this health effect.

Non-fatal heart attacks have been linked with short term exposures to $PM_{2.5}$ in the U.S. (Peters et al, 2001) and other countries (Poloniecki et al, 1997). We use a recent study by Peters et al. (2001) as the basis for the C-R function estimating the relationship between $PM_{2.5}$ and non-fatal heart attacks in adults. Peters et al is the only available U.S. study to provide a specific estimate for heart attacks. Other studies, such as Samet et al (2000) and Moolgavkar et al (2000) show a consistent relationship between all cardiovascular hospital admissions, including for non-fatal heart attacks, and PM. Given the lasting impact of a heart attack on longer-term health costs and earnings, we choose to provide a separate estimate for non-fatal heart attacks based on the single available U.S. C-R function. The finding of a specific impact on heart attacks is consistent with hospital admission and other studies showing relationships between fine particles and cardiovascular effects both within and outside the U.S. These studies provide a weight of evidence for this type of effect. Several epidemiologic studies (Liao et al, 1999; Gold et al, 2000;

Magari et al, 2001) have shown that heart rate variability (an indicator of how much the heart is able to speed up or slow down in response to momentary stresses) is negatively related to PM levels. Heart rate variability is a risk factor for heart attacks and other coronary heart diseases (Carthenon et al, 2002; Dekker et al, 2000; Liao et al, 1997, Tsuji et al. 1996). As such, significant impacts of PM on heart rate variability is consistent with an increased risk of heart attacks.

9.3.4 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore willingness-to-pay (WTP) for changes in risk prior to the regulation (Freeman, 1993). For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as a primary estimate. These costs of illness (COI) estimates generally understate the true value of reductions in risk of a health effect, reflecting the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect (Harrington and Portney, 1987; Berger, 1987). Unit values for health endpoints are provided in Table 9-7. All values are in constant year 2000 dollars.

It is currently unknown whether there is a delay between changes in chronic PM exposures and changes in mortality rates. The existence of such a time lag is important for the valuation of premature mortality incidences as economic theory suggests benefits occurring in the future should be discounted relative to benefits occurring today. Although there is no specific scientific evidence of a PM effects lag, current scientific literature on adverse health effects associated with smoking and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure would not occur in the same year as the exposure reduction. This literature implies that lags of a few years or longer are plausible. For our base estimate, we have assumed a five-year distributed lag structure, with 25 percent of premature deaths occurring in the first year, another 25 percent in the second year, and 16.7 percent in each of the remaining three years. To account for the preferences of individuals for current risk reductions relative to future risk reductions, we discount the value of avoided premature mortalities occurring beyond the analytical year (2020 or 2030) using three and seven percent discount rates. No lag adjustment is necessary for the alternative estimate, which focuses on premature mortality occurring within a few days of the PM exposure.

Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. The economics literature suggests that the severity of a health effect is a primary determinant of the strength of the relationship between changes in real income and WTP (Alberini, 1997; Miller, 2000; Evans and Viscusi, 1993). As such, we use different factors to adjust the WTP for minor health effects, severe and chronic health effects, and premature mortality. We also adjust WTP for improvements in recreational visibility. Adjustment factors used to account for projected growth in real income from 1990 to 2030 are 1.09 for minor health effects, 1.33 for severe and chronic health effects, 1.29 for premature mortality, and 1.79 for recreational visibility. Adjustment factors for 2020 are 1.08 for minor health effects, 1.30 for severe and chronic health effects, 1.26 for premature mortality, and 1.70 for recreational visibility. Note that due to a lack of reliable projections of income growth past 2024, we assume constant WTP from 2024 through 2030. This will result in an underestimate of benefits occurring between 2024 and 2030. Details of the calculation of the income adjustment factors are provided in Appendix 9A.

For two endpoints, premature mortality and chronic bronchitis, we provide both a base valuation estimate, reflecting the best available scientific literature and methods, and an alternative estimate, reflecting different assumptions about the value of reducing risks of premature death and chronic bronchitis. Following the advice of the Environmental Economics Advisory Committee of the Science Advisory Board, the base estimate uses the VSL approach in calculating the primary estimate of mortality benefits, because we believe this calculation to provide the most reasonable single estimate of an individual's willingness to trade off money for reductions in mortality risk (EPA-SAB-EEAC-00-013). The mean value of avoiding one statistical death (the VSL) is estimated to be $6.3 million in constant 2000 dollars. This represents an intermediate value from a variety of estimates that appear in the economics literature, and it is a value EPA has frequently used in RIAs for other rules and in the Section 812 Reports to Congress. The Alternative Estimate reflects the impact of changes to key assumptions associated with the valuation of mortality. These include: 1)an alternaive interpretation of the literature on monetary valuation of VSL, 2) the use of a value of a statistical life years rather than a VSL approach, and 3) the degree of prematurity (number of statistical life years lost) for mortalities from air pollution.

9.3.5 Welfare Effects

Our analysis examines two categories of welfare effects: visibility in a subset of national parks and changes in consumer and producer surplus associated with changes in agricultural yields. There are a number of other environmental effects which may affect human welfare, but due to a lack of appropriate physical effects or valuation methods, we are unable to quantify or monetize these effects for our analysis of the nonroad standards.

9.3.5.1 Visibility Benefits

Changes in the level of ambient particulate matter caused by the reduction in emissions from the preliminary control options will change the level of visibility in much of the U.S. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Grand Canyon.

For the purposes of this analysis, visibility improvements were valued only for a limited set of mandatory federal Class I areas. Benefits of improved visibility in the places people live, work, and recreate outside of these limited set of Class I areas were not included in our estimate of total benefits, although they are examined in a sensitivity analysis presented in Appendix 9B. All households in the U.S. are assumed to derive some benefit from improvements in Class I areas, given their national importance and high visitation rates from populations throughout the U.S. However, values are assumed to be higher if the Class I area is located close to their home.[F] We use the results of a 1988 contingent valuation survey on recreational visibility value (Chestnut and Rowe, 1990a; 1990b) to derive values for visibility improvements. The Chestnut and Rowe study measured the demand for visibility in Class I areas managed by the National Park Service (NPS) in three broad regions of the country: California, the Southwest, and the Southeast. The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the U.S. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions. However, these values are less certain and are thus presented only as an sensitivity estimate in Appendix 9B.

A general willingness to pay equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from the Nonroad Diesel Engine rule. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (2002), and is described in detail in the benefits technical support document (Abt Associates, 2003). One major source of uncertainty for the visibility benefit estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for willingness to pay for the affected population could have significant effects on the size of the estimates. Assumptions about how individuals respond to changes in visibility that are either very small, or outside the range covered in the Chestnut and Rowe study, could also affect the results.

9.3.5.2 Agricultural Benefits

Laboratory and field experiments have shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using the AGSIM© agricultural benefits model (Taylor, et al., 1993). AGSIM© is an econometric-simulation model that is based on a large set of statistically estimated demand and supply equations for agricultural commodities produced in the United States.

The model employs biological exposure-response information derived from controlled experiments conducted by the NCLAN (NCLAN, 1996). For the purpose of our analysis, we analyze changes for the six most economically significant crops for which C-R functions are

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[F] For details of the visibility estimates discussed in this section, please refer to the benefits technical support document for this RIA (Abt Associates 2003).

available: corn, cotton, peanuts, sorghum, soybean, and winter wheat. For some crops there are multiple C-R functions, some more sensitive to ozone and some less. Our base estimate assumes that crops are evenly mixed between relatively sensitive and relatively insensitive varieties.

The measure of benefits calculated by the AGSIM© model is the net change in consumer and producer surplus from baseline ozone concentrations to the ozone concentrations resulting from emission reductions. Using the baseline and post-control equilibria, the model calculates the change in net consumer and producer surplus on a crop-by-crop basis. Dollar values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with changes in ambient ozone.

9.3.5.3 Other Welfare Benefits

Ozone also has been shown conclusively to cause discernible injury to forest trees (US EPA, 1996; Fox and Mickler, 1996). In our previous analysis of the HD Engine/Diesel Fuel rule, we were able to quantify the effects of changes in ozone concentrations on tree growth for a limited set of species. Due to data limitations, we were not able to quantify such impacts for this analysis. We plan to assess both physical impacts on tree growth and the economic value of those physical impacts in our analysis of the final rule. We will use econometric models of forest product supply and demand to estimate changes in prices, producer profits and consumer surplus.

An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the U.S. is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (US EPA, 1996c, p. 5-521). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted.

The proposed nonroad diesel standards, by reducing NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects.

The nonroad diesel standards are also expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. Criteria pollutants also have corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefit analyses have been able to provide quantitative estimates of household soiling damage. Consistent with SAB advice, we determined that the existing data (based on consumer expenditures from the early 1970's) are too out of date to provide a reliable enough estimate of current household soiling damages (EPA-SAB-Council-ADV-003, 1998) to include in our base estimate. We calculate household soiling damages in a sensitivity estimate provided in Appendix 9B.

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994) indicate that these benefits could be an order of magnitude larger than household soiling benefits.

Reductions in emissions of diesel hydrocarbons that result in unpleasant odors may also lead to improvements in public welfare. The magnitude of this benefit is very uncertain, however, Lareau and Rae (1989) found a significant and positive WTP to reduce the number of exposures to diesel odors. They found that households were on average willing to pay around \$20 to \$27 (2000\$) per year for a reduction of one exposure to intense diesel odors per week (translating this to a national level, for the approximately 125 million households in 2020, the total WTP would be between \$2.5 and \$3.4 billion annually). Their results are not in a form that can be transferred to the context of this analysis, but the general magnitude of their results suggests this could be a significant welfare benefit of the rule.

The effects of air pollution on the health and stability of ecosystems are potentially very important, but are at present poorly understood and difficult to measure. The reductions in NO_X caused by the proposed rule could produce significant benefits. Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Bricker et al., 1999).

Direct C-R functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP based measure of benefits depends on the availability of these C-R functions and on estimates of the value of environmental responses. Because neither appropriate C-R functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible.

If better models of ecological effects can be defined, EPA believes that progress can be made in estimating WTP measures for ecosystem functions. For example, if nitrogen or sulfate loadings can be linked to measurable and definable changes in fish populations or definable indexes of biodiversity, then CV studies can be designed to elicit individuals' WTP for changes in these effects. This is an important area for further research and analysis, and will require close collaboration among air quality modelers, natural scientists, and economists.

9.3.6 Treatment of Uncertainty

In any complex analysis, there are likely to be many sources of uncertainty. This analysis is no exception. Many inputs are used to derive the final estimate of economic benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of C-R functions, estimates of values, population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Some of the key uncertainties in the benefits analysis are presented in Table 9-8. For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. For other parameters or inputs, the necessary information is not available.

In addition to uncertainty, the annual benefit estimates presented in this analysis are also inherently variable due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as hours of equipment use and weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the magnitude of benefits expected, rather than the actual benefits that would occur every year.

We present a base estimate of the total benefits, based on our interpretation of the best available scientific literature and methods and supported by the SAB and the NAS (NRC, 2002). In addition, we provide an alternative estimate based on several important alternative assumptions about the estimation and valuation of reductions in premature mortality and chronic bronchitis. We also provide sensitivity analyses to illustrate the effects of uncertainty about key analytical assumptions. Our analysis of the preliminary control options did not include formal integrated probabilistic uncertainty analyses, although we have conducted several sensitivity tests and have analyzed a full Alternative Estimate based on changes to several key model parameters. The recent NAS report on estimating public health benefits of air pollution regulations recommended that EPA begin to move the assessment of uncertainties from its ancillary analyses into its primary analyses by conducting probabilistic, multiple-source uncertainty analyses. We are working to implement these recommendations. We plan to better characterize some of this uncertainty, especially regarding mortality-related benefits in the RIA to accompany the final rule.

9.3.7 Model Results

Full implementation of the modeled preliminary control options is projected in 2020 to reduce 48-state emissions of NOx by 663,600 tons (58 percent of landbased nonroad emissions), SO_2 by 305,000 tons (98.9 percent), VOC by 23,200 tons (24 percent) and directly emitted $PM_{2.5}$ by 91,300 tons (71 percent). In 2030, the modeled preliminary control options are expected to reduce 48-state emissions of NOx by 1 million tons (82 percent), SO_2 by 359,800 tons (99.7 percent), VOC by 34,000 tons (35 percent) and direct PM by 129,000 tons (90 percent).

Based on these projected emission changes, REMSAD modeling results indicate the pollution controls generate greater absolute air quality improvements in more populated, urban areas. The rule will reduce average annual mean concentrations of $PM_{2.5}$ across the U.S. by roughly 2.5 percent (or 0.2 $\mu g/m^3$) and 3.4 percent (or 0.28 $\mu g/m^3$) in 2020 and 2030, respectively. The population-weighted average mean concentration declined by 3.3 percent (or 0.42 $\mu g/m^3$) in 2020 and 4.5 percent (or 0.59 $\mu g/m^3$) in 2030, which is much larger in absolute terms than the spatial average for both years. Table 9-9 presents information on the distribution of modeled reductions in ambient PM concentrations across populations in the U.S. By 2030, slightly over 50 percent of U.S. populations will live in areas with reductions of greater than 0.5 $\mu g/m^3$. This information indicates how widespread the improvements in PM air quality are expected to be.

Applying the C-R functions described in Table 9-5 to the estimated changes in $PM_{2.5}$ and ozone yields estimates of the number of avoided incidences for each health outcome. These estimates are presented in Table 9-10 for the 2020 and 2030 model analysis years. To provide estimates of the monetized benefits of the reductions in PM-related health outcomes described in Table 9-10, we multiply the point estimates of avoided incidences by unit values. Values for welfare effects are based on application of the economic models described above. The estimated total monetized health and welfare benefits are presented in Table 9-11.

The largest monetized health benefit is associated with reductions in the risk of premature mortality, which accounts for 90 percent of total monetized health benefits in our base estimate and over 60 percent of total monetized benefits in the alternative estimate. The next largest benefit is for chronic illness reductions (chronic bronchitis and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality in the base estimate. Minor restricted activity days, work loss days, and hospital admissions account for the majority of the remaining benefits. While the other categories account for less than $100 million each, they represent a large number of avoided incidences affecting many individuals.

Ozone benefits are in aggregate positive for the nation. However, due to ozone increases occurring during certain hours of the day in some urban areas, in 2020 the net effect is an increase in ozone-related minor restricted activity days (MRAD), which are related to changes in daily average ozone (which includes hours during which ozone levels are low, but are increased relative to the baseline). However, by 2030, there is a net decrease in ozone-related MRAD consistent with widespread reductions in ozone concentrations from the increased NOx emissions reductions. Note that in both years, the overall impact of changes in both PM and ozone is a large decrease in the number of MRAD. Overall, ozone benefits are low relative to PM benefits for similar endpoint categories because of the increases in ozone concentrations during some hours of some days in certain urban areas. For a more complete discussion of this issue, see Chapter 2.

Monetized and quantified welfare benefits are far outweighed by health benefits. However, we have not been able to quantify some important welfare categories, including the value of changes in ecosystems from reduced deposition of nitrogen and sulfur. The welfare benefits we are able to quantify are dominated by the value of improved visibility. Visibility benefits just in the limited set of parks included in the monetized total benefit estimate are over $2 billion in 2030. Agricultural benefits, while small relative to visibility benefits, are significant relative to ozone-related health benefits, representing the largest single benefit category for ozone.

Table 9-6
Endpoints and Studies Used to Calculate Total Monetized Health Benefits

Endpoint	Pollutant	Applied Population	Source of Effect Estimate(s)	Source of Baseline Incidence
Premature Mortality				
Base – Long-term exposure	$PM_{2.5}$	>29 years	Krewski, et al. (2000)	CDC Wonder (1996-1998)
Alternative – Short-term exposure	$PM_{2.5}$	all ages	Schwartz et al. (1996) adjusted using ratio of distributed lag to single day coefficients from Schwartz et al. (2000)	CDC Wonder (1996-1998)
Chronic Illness				
Chronic Bronchitis	$PM_{2.5}$	> 26 years	Abbey, et al. (1995)	1999 HIS (American Lung Association, 2002b, Table 4); Abbey et al. (1993, Table 3)
Non-fatal Heart Attacks	$PM_{2.5}$	Adults	Peters et al. (2001)	1999 NHDS public use data files; adjusted by 0.93 for prob. of surviving after 28 days (Rosamond et al., 1999)
Hospital Admissions				
Respiratory	O_3	> 64 years	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp) Schwartz (1994a, 1994b) - ICD 480-486 (pneumonia) Moolgavkar et al. (1997) - ICD 480-487 (pneumonia) Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al (1997) - ICD 490-496 (COPD)	1999 NHDS public use data files
	O_3	< 2 years	Burnett et al. (2001)	1999 NHDS public use data files
	$PM_{2.5}$	>64 years	Pooled estimate: Moolgavkar (2000) - ICD 490-496 (COPD) Lippman et al. (2000) - ICD 490-496 (COPD)	1999 NHDS public use data files
	$PM_{2.5}$	20-64 years	Moolgavkar (2000) - ICD 490-496 (COPD)	1999 NHDS public use data files
	$PM_{2.5}$	> 64 years	Lippman et al. (2000) - ICD 480-486 (pneumonia)	1999 NHDS public use data files

Table 9-6
Endpoints and Studies Used to Calculate Total Monetized Health Benefits

Endpoint	Pollutant	Applied Population	Source of Effect Estimate(s)	Source of Baseline Incidence
	$PM_{2.5}$	< 65 years	Sheppard, et al. (1999) - ICD 493 (asthma)	1999 NHDS public use data files
Cardiovascular	$PM_{2.5}$	> 64 years	Pooled estimate: Moolgavkar (2000) - ICD 390-429 (all cardiovascular) Lippman et al. (2000) - ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	1999 NHDS public use data files
	$PM_{2.5}$	20-64 years	Moolgavkar (2000) - ICD 390-429 (all cardiovascular)	1999 NHDS public use data files
Asthma-Related ER Visits	O_3	All ages	Pooled estimate: Weisel et al. (1995), Cody et al. (1992), Stieb et al. (1996)	2000 NHAMCS public use data files[3]; 1999 NHDS public use data files
	$PM_{2.5}$	0-18 years	Norris et al. (1999)	2000 NHAMCS public use data files; 1999 NHDS public use data files
Other Health Endpoints				
Acute Bronchitis	$PM_{2.5}$	8-12 years	Dockery et al. (1996)	American Lung Association (2002a, Table 11)
Upper Respiratory Symptoms	PM_{10}	Asthmatics, 9-11 years	Pope et al. (1991)	Pope et al. (1991, Table 2)
Lower Respiratory Symptoms	$PM_{2.5}$	7-14 years	Schwartz and Neas (2000)	Schwartz (1994, Table 2)
Work Loss Days	$PM_{2.5}$	18-65 years	Ostro (1987)	1996 HIS (Adams et al., 1999, Table 41); U.S. Bureau of the Census (2000)
School Absence Days	O_3	 9-10 years 6-11 years	Pooled estimate: Gilliland et al (2001) Chen et al (2000)	National Center for Education Statistics (1996)
Worker Productivity	O_3	Outdoor workers, 18-65	Crocker and Horst (1981) and U.S. EPA (1984)	NA
Minor Restricted Activity Days	$PM_{2.5}$, O_3	18-65 years	Ostro and Rothschild (1989)	Ostro and Rothschild (1989, p. 243)

Table 9-7
Unit Values Used for Economic Valuation of Health Endpoints (2000$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level	2030 Income Level	
Premature Mortality				Base value is the mean of VSL estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the Section 812 Costs and Benefits of the Clean Air Act, 1990-2010 (US EPA, 1999). Alternative VSLY estimates are derived from a VSL based on the mean of VSL estimates from the 5 contingent valuation studies referenced above. VSLY for populations under 65 are based on 35 years of assumed average remaining life expectancy. VSLY for populations 65 and older are based on 10 years of assumed average remaining life expectancy.
Base Estimate (VSL)	$6,300,000	$8,000,000	$8,100,000	
Alternative Estimate (VSLY)				
<u>3% discount rate</u>				
Under 65	$172,000	$217,000	$221,000	
65 and older	$434,000	$547,000	$559,000	
<u>7% discount rate</u>				
Under 65	$286,000	$360,000	$368,000	
65 and older	$527,000	$664,000	$678,000	
Chronic Bronchitis (CB)				Base value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB. Alternative value is a cost of illness (COI) estimate based on Cropper and Krupnick (1990). Includes both medical costs and opportunity cost from age of onset to expected age of death (assumes that chronic bronchitis does not change life expectancy).
Base Estimate	$340,000	$430,000	$440,000	
Alternative Estimate				
<u>3% discount rate</u>				
Age 27-44	$150,542	$150,542	$150,542	
Age 45-64	$97,610	$97,610	$97,610	
Age 65 and older	$11,088	$11,088	$11,088	
<u>7% discount rate</u>				
Age 27-44	$86,026	$86,026	$86,026	
Age 45-64	$72,261	$72,261	$72,261	
Age 65 and older	$9,030	$9,030	$9,030	

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level	2030 Income Level	
Non-fatal Myocardial Infarction (heart attack)				Age specific cost-of-illness values reflecting lost earnings and direct medical costs over a 5 year period following a non-fatal MI. Lost earnings estimates based on Cropper and Krupnick (1990). Direct medical costs based on simple average of estimates from Russell et al. (1998) and Wittels et al. (1990). Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 yrs of lost earnings: age of onset: at 3% at 7% 25-44 $8,774 $7,855 45-54 $12,932 $11,578 55-65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al., 1990 ($102,658 – no discounting) 2. Russell et al., 1998, 5-yr period. ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
3% discount rate				
Age 0-24	$66,902	$66,902	$66,902	
Age 25-44	$74,676	$74,676	$74,676	
Age 45-54	$78,834	$78,834	$78,834	
Age 55-65	$140,649	$140,649	$140,649	
Age 66 and over	$66,902	$66,902	$66,902	
7% discount rate				
Age 0-24	$65,293	$65,293	$65,293	
Age 25-44	$73,149	$73,149	$73,149	
Age 45-54	$76,871	$76,871	$76,871	
Age 55-65	$132,214	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	$65,293	
Hospital Admissions				
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Asthma admissions	$6,634	$6,634	$6,634	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level	2030 Income Level	
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Emergency room visits for asthma	$286	$286	$286	Simple average of two unit COI values: (1) $311.55, from Smith et al., 1997, and (2) $260.67, from Stanford et al., 1999.
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope, et al. result in 7 different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz, et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Acute Bronchitis	$360	$390	$390	Assumes a 6 day episode, with daily value equal to the average of low and high values for related respiratory symptoms recommended in Neumann, et al. 1994.
Restricted Activity and Work/School Loss Days				
Work Loss Days (WLDs)	Variable (national median = $115)			County-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5 – to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level	2030 Income Level	
School Absence Days	$75	$75	$75	Based on expected lost wages from parent staying home with child. Estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103. The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75.
Worker Productivity	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	Based on $68 – median daily earnings of workers in farming, forestry and fishing – from Table 621, Statistical Abstract of the United States ("Full-Time Wage and Salary Workers – Number and Earnings: 1985 to 2000") (Source of data in table: U.S. Bureau of Labor Statistics, Bulletin 2307 and Employment and Earnings, monthly).
Minor Restricted Activity Days (MRADs)	$51	$55	$56	Median WTP estimate to avoid one MRAD from Tolley, et al. (1986) .

Table 9-8
Primary Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions
– The value of the ozone- or PM-coefficient in each C-R function. – Application of a single C-R function to pollutant changes and populations in all locations. – Similarity of future year C-R relationships to current C-R relationships. – Correct functional form of each C-R relationship. – Extrapolation of C-R relationships beyond the range of ozone or PM concentrations observed in the study. – Application of C-R relationships only to those subpopulations matching the original study population.
2. Uncertainties Associated With Ozone and PM Concentrations
– Responsiveness of the models to changes in precursor emissions resulting from the control policy. – Projections of future levels of precursor emissions, especially ammonia and crustal materials. – Model chemistry for the formation of ambient nitrate concentrations. – Lack of ozone monitors in rural areas requires extrapolation of observed ozone data from urban to rural areas. – Use of separate air quality models for ozone and PM does not allow for a fully integrated analysis of pollutants and their interactions. – Full ozone season air quality distributions are extrapolated from a limited number of simulation days. – Comparison of model predictions of particulate nitrate with observed rural monitored nitrate levels indicates that REMSAD overpredicts nitrate in some parts of the Eastern US and underpredicts nitrate in parts of the Western US.
3. Uncertainties Associated with PM Mortality Risk
– No scientific literature supporting a direct biological mechanism for observed epidemiological evidence. – Direct causal agents within the complex mixture of PM have not been identified. – The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. – The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. – Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects
– The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated With Baseline Incidence Rates
– Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates. – Current baseline incidence rates may not approximate well baseline incidence rates in 2030. – Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated With Economic Valuation
– Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. – Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors. – Future markets for agricultural products are uncertain.
7. Uncertainties Associated With Aggregation of Monetized Benefits
– Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified or unmonetized benefits are not included.

Table 9-9
Distribution of PM2.5 Air Quality Improvements Over Population
Due to Nonroad Engine/Diesel Fuel Standards: 2020 and 2030

Change in Annual Mean $PM_{2.5}$ Concentrations ($\mu g/m^3$)	*2020 Population*		*2030 Population*	
	Number (millions)	*Percent (%)*	*Number (millions)*	*Percent (%)*
0 > Δ $PM_{2.5}$ Conc ≤ 0.25	65.11	19.75%	28.60	8.04%
0.25 > Δ $PM_{2.5}$ Conc ≤ 0.5	184.52	55.97%	147.09	41.33%
0.5 > Δ $PM_{2.5}$ Conc ≤ 0.75	56.66	17.19%	107.47	30.20%
0.75 > Δ $PM_{2.5}$ Conc ≤ 1.0	14.60	4.43%	38.50	10.82%
1.0 > Δ $PM_{2.5}$ Conc ≤ 1.25	5.29	1.60%	8.82	2.48%
1.25 > Δ $PM_{2.5}$ Conc ≤ 1.5	3.51	1.06%	15.52	4.36%
1.5 > Δ $PM_{2.5}$ Conc ≤ 1.75	0	0.00%	5.70	1.60%
Δ $PM_{2.5}$ Conc > 1.75	0	0.00%	4.19	1.18%

[a] The change is defined as the control case value minus the base case value.

Table 9-10
Reductions in Incidence of Adverse Health Effects Associated with Reductions in Particulate Matter and Ozone Due to the Modeled Preliminary Nonroad Engine Standards

Endpoint	Avoided Incidence[A] (cases/year)	
	2020	**2030**
PM-related Endpoints		
Premature mortality[B] -		
Base estimate: Long-term exposure (adults, 30 and over)	6,200	11,000
Alternative estimate: Short-term exposure (all ages)	3,700	6,600
Chronic bronchitis (adults, 26 and over)	4,300	6,500
Non-fatal myocardial infarctions (adults, 18 and older)	11,000	18,000
Hospital admissions – Respiratory (all ages)[C]	3,100	5,500
Hospital admissions – Cardiovascular (adults, 20 and older)[D]	3,300	5,700
Emergency Room Visits for Asthma (18 and younger)	4,300	6,500
Acute bronchitis (children, 8-12)	10,000	16,000
Lower respiratory symptoms (children, 7-14)	110,000	170,000
Upper respiratory symptoms (asthmatic children, 9-11)	92,000	120,000
Work loss days (adults, 18-65)	780,000	1,100,000
Minor restricted activity days (adults, age 18-65)	4,600,000	6,500,000
Ozone-related Endpoints		
Hospital Admissions – Respiratory Causes (adults, 65 and older)[E]	370	1,100
Hospital Admissions - Respiratory Causes (children, under 2 years)	150	280
Emergency Room Visits for Asthma (all ages)	93	200
Minor restricted activity days (adults, age 18-65)	(2,400)	96,000
School absence days (children, age 6-11)	65,000	96,000

[A] Incidences are rounded to two significant digits.
[B] Premature mortality associated with ozone is not separately included in this analysis
[C] Respiratory hospital admissions for PM includes admissions for COPD, pneumonia, and asthma.
[D] Cardiovascular hospital admissions for PM includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.
[E] Respiratory hospital admissions for ozone includes admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 9-11
Results of Human Health and Welfare Benefits Valuation for the Modeled Preliminary Nonroad Diesel Engine Standards

Endpoint	Pollutant	Monetary Benefits[A,B] (millions 2000$, Adjusted for Income Growth)	
		2020	2030
Premature mortality[C]	PM		
Base estimate: Long-term exposure, (adults, 30 and over)			
3% discount rate		$47,000	$85,000
7% discount rate		$44,000	$80,000
Alternative estimate: Short-term exposure, (all ages)			
3% discount rate		$7,200	$13,000
7% discount rate		$8,200	$15,000
Chronic bronchitis (adults, 26 and over)	PM		
Base estimate: Willingness-to-pay		$1,900	$3,000
Alternative estimate: Cost-of-illness			
3% discount rate		$420	$600
7% discount rate		$270	$390
Non-fatal myocardial infarctions	PM		
3% discount rate		$900	$1,400
7% discount rate		$870	$1,400
Hospital Admissions from Respiratory Causes	O_3 and PM	$55	$110
Hospital Admissions from Cardiovascular Causes	PM	$72	$120
Emergency Room Visits for Asthma	O_3 and PM	$1	$2
Acute bronchitis (children, 8-12)	PM	$4	$6
Lower respiratory symptoms (children, 7-14)	PM	$2	$3
Upper respiratory symptoms (asthmatic children, 9-11)	PM	$2	$3
Work loss days (adults, 18-65)	PM	$110	$150
Minor restricted activity days (adults, age 18-65)	O_3 and PM	$250	$370
School absence days (children, age 6-11)	O_3	$5	$10
Worker productivity (outdoor workers, age 18-65)	O_3	$4	$7
Recreational visibility (86 Class I Areas)	PM	$1,400	$2,200
Agricultural crop damage (6 crops)	O_3	$89	$140
Monetized Total[H]	O_3 and PM		
Base estimate			
3% discount rate		$52,000+B	$92,000+B
7% discount rate		$49,000+B	$87,000+B
Alternative estimate			
3% discount rate		$11,000+B	$19,000+B
7% discount rate		$11,000+B	$20,000+B

[A] Monetary benefits are rounded to two significant digits.

[B] Monetary benefits are adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030).

[C] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants. Also note that the valuation assumes the 5 year distributed lag structure described earlier. Results reflect the use of two different discount rates; a 3% rate which is recommended by EPA's Guidelines for Preparing Economic Analyses (US EPA, 2000c), and 7% which is recommended by OMB Circular A-94 (OMB, 1992).

[D] Respiratory hospital admissions for PM includes admissions for COPD, pneumonia, and asthma.

[E] Cardiovascular hospital admissions for PM includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[F] Respiratory hospital admissions for ozone includes admissions for all respiratory causes and subcategories for COPD and pneumonia.

[G] B represents the monetary value of the unmonetized health and welfare benefits. A detailed listing of unquantified PM, ozone, CO, and NMHC related health effects is provided in Table 9.1.

9.3.8 Apportionment of Benefits to NOx, SO_2, and PM Emissions Reductions

As noted in the introduction to this chapter, the proposed standards differ from those that we used in modeling air quality and economic benefits. As such, it is necessary for us to scale the modeled benefits to reflect the difference in emissions reductions between the proposed and preliminary modeled standards. In order to do so, however, we must first apportion total benefits to the NOx, SO_2, and direct PM reductions for the modeled preliminary control options. This apportionment is necessary due to the differential contribution of each emission species to the total change in ambient PM and total benefits. We do not attempt to develop scaling factors for ozone benefits because of the difficulty in separating the contribution of NOx and NMHC/VOC reductions to the change in ozone concentrations.

PM is a complex mixture of particles of varying species, including nitrates, sulfates, and primary particles, including organic and elemental carbon. These particles are formed in complex chemical reactions from emissions of precursor pollutants, including NOx, SO_2, ammonia, hydrocarbons, and directly emitted particles. Different emissions species contribute to the formation of PM in different amounts, so that a ton of emissions of NOx contributes to total ambient PM mass differently than a ton of SO_2 or directly emitted PM. As such, it is inappropriate to scale benefits by simply scaling the sum of all precursor emissions. A more appropriate scaling method is to first apportion total PM benefits to the changes in underlying emission species and then scale the apportioned benefits.

PM formation relative to any particular reduction in an emission species is a highly nonlinear process, depending on meteorological conditions and baseline conditions, including the amount of available ammonia to form ammonium nitrate and ammonium sulfate. Given the limited air quality modeling conducted for this analysis, we make several simplifying assumptions about the contributions of emissions reductions for specific species to changes in particle species. For this exercise, we assume that changes in sulfate particles are attributable to changes in SO_2 emissions, changes in nitrate particles are attributable to changes in NOx emissions, and changes in primary PM are attributable to changes in direct PM emissions. These assumptions essentially assume independence between SO_2, NOx, and direct PM in the formation of ambient PM. This is a reasonable assumption for direct PM, as it is generally not reactive in the atmosphere. However, SO_2 and NOx emissions interact with other compounds in the atmosphere to form $PM_{2.5}$. For example, ammonia reacts with SO_2 first to form ammonium sulfate. If there is remaining ammonia, it reacts with NOx to form ammonium nitrate. When SO_2 alone is reduced, ammonia is freed to react with any NOx that has not been used in forming ammonium nitrate. If NOx is also reduced, then there will be less available NOx to form ammonium nitrate from the newly available ammonia. Thus, reducing SO_2 can potentially lead to decreased ammonium sulfate and increased nitrate, so that overall ambient PM benefits are less than the reduction in sulfate particles. If NOx alone is reduced, there will be a direct reduction in ammonium nitrate, although the amount of reduction depends on whether an area is ammonia limited. If there is not enough ammonia in an area to use up all of the available NOx, then NOx reductions will only have an impact if they reduce emissions to the point where ammonium nitrate formation will be affected. NOx reductions will not result in any offsetting increases in ambient PM under most conditions. The implications of this for apportioning benefits between NOx, SO_2, and direct PM is that some of the sulfate related benefits will be offset by reductions in nitrate benefits, so benefits from SO_2 reductions will be overstated, while NOx benefits will be understated. It is not immediately apparent the size of this bias.

The measure of change in ambient particle mass that is most related to health benefits is the population-weighted change in $PM_{2.5}$ $\mu g/m^3$, because health benefits are driven both by the size of the change in $PM_{2.5}$ and the populations exposed to that change. We calculate the proportional share of total change in mass accounted for by nitrate, sulfate, and primary particles. Results of these calculations for the 2020 and 2030 REMSAD modeling analysis are presented in Table 9-12. The sulfate percentage of total change is used to represent the SO_2 contribution to health benefits, the nitrate percentage is used to represent the NOx contribution to health benefits, and the primary PM percentage is used to represent the direct PM contribution to health benefits. These percentages will be applied to the PM-related health benefits estimates in Table 9-10 and 9-11 and combined with the emission scaling factors developed in section 9.2 to estimate benefits for the proposed standards.

Table 9-12. Apportionment of Population Weighted Change in Ambient PM2.5 to Nitrate, Sulfate, and Primary Particles

	2020		2030	
	Population-weighted Change (µg/m3)	Percent of Total Change	Population-weighted Change (µg/m3)	Percent of Total Change
Total PM2.5	0.316		0.438	
Sulfate	0.071	22.5%	0.090	20.5%
Nitrate	0.041	13.1%	0.073	16.8%
Primary PM	0.203	64.4%	0.274	62.7%

Visibility benefits are highly specific to the parks at which visibility improvement occur, rather than where populations live. As such, it is necessary to scale benefits at each individual park and then aggregate to total scaled visibility benefits. We apportion benefits at each park using the contribution of changes in sulfates, nitrates, and primary particles to changes in light extinction. The change in light extinction at each park is determined by the following equation (Sisler, 1996):

$$\Delta\beta_{EXT} = [3F(rh) * 1.375 * \Delta TSO4] + [3F(rh) * 1.29 * \Delta PNO3] + 10 * \Delta PEC + 4 * \Delta TOA + \Delta PMFINE + 0.6 * \Delta PMCOARSE$$

where rh is relative humidity, ΔTSO4 is the change in particulate sulfate, ΔPNO3 is the change in particulate nitrate, ΔPEC is the change in primary elemental carbon, ΔTOA is the change in total organic aerosols, ΔPMFINE is the change in primary fine particles, and ΔPMCOARSE is the change in primary coarse particles.

The proportion of the total change in light extinction associated with changes in sulfate particles is $[3F(rh) * 1.375 * \Delta TSO4]/\Delta\beta_{EXT}$. The proportion of the total change in light extinction associated with changes in nitrate particles is $[3F(rh) * 1.29 * \Delta PNO3]/\Delta\beta_{EXT}$. Finally, the proportion of the total change in light extinction associated with the change in directly emitted particles is $[10 * \Delta PEC + 4 * \Delta TOA + \Delta PMFINE + 0.6 * \Delta PMCOARSE]/\Delta\beta_{EXT}$.

We calculate these proportions for each park to apportion park specific benefits between SO_2, NOx, and PM. The apportioned benefits are then scaled using the emission ratios in Table 9-5. Park specific apportionment of benefits is detailed in Appendix 9C.

9.4 Estimated Benefits of Proposed Nonroad Diesel Engine Standards in 2020 and 2030

To estimate the benefits of the NOx, SO_2, and direct PM emission reductions from the proposed standards in 2020 and 2030, we apply the emissions scaling factors derived in section 9.2 and the apportionment factors described in section 9.3 to the benefits estimates for 2020 and 2030 listed in Tables 9-10 and 9-11. Note that we apply scaling and apportionment factors only to PM and visibility related endpoints. Ozone related health and welfare benefits are not estimated for the emissions reductions associated with the proposed standards for reasons noted in the introduction to this chapter.

The scaled avoided incidence estimate for any particular health endpoint is calculated using the following equation:

$$Scaled\ Incidence = Modeled\ Incidence * \sum_i R_i A_i ,$$

where Ri is the emissions ratio for emission species i from Table 9-4, and Ai is the health benefits apportionment factor for emission species i, from Table 9-12. Essentially, benefits are scaled using a weighted average of the species specific emissions ratios. For example, the calculation of the avoided incidence of premature mortality for the base estimate in 2020 is:

Scaled Premature Mortality Incidence = 6,200 * (0.759*0.129 + 0.800*0.224 + 0.869*0.647) = 5,200

The monetized value for each endpoint is then obtained simply by multiplying the scaled incidence estimate by the appropriate unit value in Table 9-6. The estimated changes in incidence of health effects in 2020 and 2030 for the proposed rule based on application of the weighted scaling factors are presented in Table 9-13. The estimated monetized benefits for both PM health and visibility benefits are presented in Table 9-14. The visibility benefits are based on application of the weighted scaling factors for visibility at each Class I area in the Chestnut and Rowe study regions, aggregated to a national total for each year.

Table 9-13.
Reductions in Incidence of PM-related Adverse Health Effects Associated with the Proposed Nonroad Diesel Engine Standards

Endpoint	**Avoided Incidence[A] (cases/year)**	
	2020	**2030**
Premature mortality[B] - Base estimate: Long-term exposure (adults, 30 and over) Alternative estimate: Short-term exposure (all ages)	 5,200 3,100	 9,600 5,800
Chronic bronchitis (adults, 26 and over)	3,600	5,700
Non-fatal myocardial infarctions (adults, 18 and older)	9,200	16,000
Hospital admissions – Respiratory (adults, 20 and older)[C]	2,400	4,500
Hospital admissions – Cardiovascular (adults, 20 and older)[D]	1,900	3,800
Emergency Room Visits for Asthma (18 and younger)	3,600	5,700
Acute bronchitis (children, 8-12)	8,400	14,000
Lower respiratory symptoms (children, 7-14)	92,000	150,000
Upper respiratory symptoms (asthmatic children, 9-11)	77,000	110,000
Work loss days (adults, 18-65)	650,000	960,000
Minor restricted activity days (adults, age 18-65)	3,900,000	5,700,000

[A] Incidences are rounded to two significant digits.

[B] Premature mortality associated with ozone is not separately included in this analysis

[C] Respiratory hospital admissions for PM includes admissions for COPD, pneumonia, and asthma.

[D] Cardiovascular hospital admissions for PM includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 9-14. Results of Human Health and Welfare Benefits Valuation for the Proposed Nonroad Diesel Engine Standards

Endpoint	Monetary Benefits[A,B] (millions 2000$, Adjusted for Income Growth)	
	2020	2030
Premature mortality[C]		
Base estimate: Long-term exposure, (adults, 30 and over)		
3% discount rate (over 5 year cessation lag)	$39,000	$74,000
7% discount rate (over 5 year cessation lag)	$37,000	$70,000
Alternative estimate: Short-term exposure, (all ages)		
3% discount rate	$6,100	$12,000
7% discount rate	$6,800	$13,000
Chronic bronchitis (adults, 26 and over)[D]		
Base estimate: Willingness-to-pay	$1,600	$2,600
Alternative estimate: Cost-of-illness		
3% discount rate (over lifetime with disease)	$350	$530
7% discount rate (over lifetime with disease)	$220	$340
Non-fatal myocardial infarctions[E]		
3% discount rate (over 5 year follow up)	$750	$1,300
7% discount rate (over 5 year follow up)	$730	$1,200
Hospital Admissions from Respiratory Causes[F]	$38	$74
Hospital Admissions from Cardiovascular Causes[G]	$40	$80
Emergency Room Visits for Asthma	$1	$2
Acute bronchitis (children, 8-12)	$3	$5
Lower respiratory symptoms (children, 7-14)	$2	$3
Upper respiratory symptoms (asthmatic children, 9-11)	$2	$3
Work loss days (adults, 18-65)	$90	$130
Minor restricted activity days (adults, age 18-65)	$210	$320
Recreational visibility (86 Class I Areas)	$1,200	$1,900
Monetized Total[H]		
Base estimate		
3% discount rate	$43,000+B	$81,000+B
7% discount rate	$41,000+B	$76,000+B
Alternative estimate		
3% discount rate	$8,700+B	$16,000+B
7% discount rate	$9,300+B	$17,000+B

[A] Monetary benefits are rounded to two significant digits.

[B] Monetary benefits are adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030).

[C] Valuation of base estimate assumes discounting over the 5 year distributed lag structure described earlier. Valuation of alternative estimate assumes value of a statistical life year derived from amortization of $3.7 million value of statistical life over age group-specific remaining life expectancy. Results reflect the use of two different discount rates; a 3% rate which is recommended by EPA's Guidelines for Preparing Economic Analyses (US EPA, 2000c), and 7% which is recommended by OMB Circular A-94 (OMB, 1992).

[D] Alternative estimate assumes costs of illness and lost earnings in later life years are discounted using either 3 or 7 percent.

[E] Estimates assume costs of illness and lost earnings in later life years are discounted using either 3 or 7 percent

[F] Respiratory hospital admissions for PM includes admissions for COPD, pneumonia, and asthma.

[G] Cardiovascular hospital admissions for PM includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[H] B represents the monetary value of the unmonetized health and welfare benefits. A detailed listing of unquantified PM, ozone, CO, and NMHC related health effects is provided in Table 9-1.

9.5 Development of Intertemporal Scaling Factors and Calculation of Benefits Over Time

To estimate the health and visibility benefits of the NOx, SO_2, and direct PM emission reductions from the proposed standards occurring in years other than 2020 and 2030, it is necessary to develop factors to scale the modeled benefits in 2020 and 2030. In addition to scaling based on the relative reductions in NOx, SO_2, and direct PM, intertemporal scaling requires additional adjustments to reflect population growth, changes in the age composition of the population, and per capita income levels.

Two separate sets of scaling factors are required, one for PM related health benefits, and one for visibility benefits. For the first of these, PM health benefits, we need scaling factors based on ambient $PM_{2.5}$. Because of the nonproportional relationship between precursor emissions and ambient concentrations of $PM_{2.5}$, it is necessary to first develop estimates of the marginal contribution of reductions in each emission species to reductions in $PM_{2.5}$ in each year. Because we have only two points (2020 and 2030), we assume a very simple linear function for each species over time (assuming that the marginal contribution of each emission species to $PM_{2.5}$ is independent of the other emission species) again assuming that sulfate changes are primarily associated with SO_2 emission reductions, nitrate changes are primarily associated with NOx emission reductions, and primary PM changes are associated with direct PM emission reductions.

Using the linear relationship, we estimate the marginal contribution of SO_2 to sulfate, NOx to nitrate, and direct PM to primary PM in each year. These marginal contribution estimates are presented in Table 9-15. Note that these projections do not take into account differences in overall baseline proportions of NOx, SO_2, and PM. They assume that the change in the relative effectiveness of each emission species in reducing ambient PM that is observed between 2020 and 2030 can be extrapolated to other years. Because baseline emissions of NOx, SO_2, and PM, as well as ammonia and VOCs are changing between years, the relative effectiveness of NOx and SO_2 emission reductions may change in a non-linear fashion. It is not clear what overall biases these nonlinearities will introduce into the scaling exercise.

Multiplying the year specific marginal contribution estimates by the appropriate emissions reductions in each year yields estimates of the population weighted changes in $PM_{2.5}$ constituent species, which are summed to obtain year specific population weighted changes in total $PM_{2.5}$. Total benefits in each specific year are then developed by scaling total benefits in a base year using the ratio of the change in $PM_{2.5}$ in the target year to the base year, with additional scaling factors to account for growth in total population, age composition of the population, and growth in per capita income.

Table 9-15. Projected Marginal Contribution of Reductions in Emission Species to Reductions in Ambient PM2.5

	Change in PM2.5 species (population weighted µg/m^3 per million tons reduced)		
Year	Sulfate/SO_2	Nitrate/NOx	Primary PM/direct PM
2007	0.153	0.049	2.130
2008	0.154	0.050	2.123
2009	0.156	0.051	2.117
2010	0.157	0.052	2.111
2011	0.159	0.053	2.105
2012	0.160	0.054	2.098
2013	0.161	0.055	2.092
2014	0.163	0.056	2.086
2015	0.164	0.057	2.080
2016	0.166	0.058	2.073
2017	0.167	0.059	2.067
2018	0.169	0.060	2.061
2019	0.170	0.061	2.054
2020	0.171	0.062	2.048
2021	0.173	0.063	2.042
2022	0.174	0.064	2.036
2023	0.176	0.065	2.029
2024	0.177	0.066	2.023
2025	0.179	0.067	2.017
2026	0.180	0.069	2.011
2027	0.181	0.070	2.004
2028	0.183	0.071	1.998
2029	0.184	0.072	1.992
2030	0.186	0.073	1.985

Growth in population and changes in age composition are accounted for by apportioning total benefits into benefits accruing to three different age groups, 0 to 18, 19 to 64, and 65 and older. Benefits for each age group are then adjusted by the ratio of the age group population in the target year to the age group population in the base year. Age composition adjusted estimates are then reaggregated to obtain total population and age composition adjusted benefits for each year. Growth in per capita income is accounted for by multiplying the target year estimate by the ratio of the income adjustment factors in the target year to those in the base year.

For example, for the target year of 2010, there are 1,007 tons of NOx reductions, 270,977 tons of SO_2 reductions, and 21,864 tons of PM reductions. These are associated with a populated weighted change in total $PM_{2.5}$ of 0.089, calculated from Table 9-15. The ratio of this change to the change in the 2030 base year is 0.202. The age group apportionment factors (based on the Base estimate using a 3% discount rate for 2030) are 0.02% for 0 to 18, 19.4% for 19 to 64, and 80.6% for 65 and older. The age group population growth ratios for 2010 relative to 2030 are 0.88 for 0 to 18, 0.96 for 19 to 64, and 0.55 for 65 and older. The income growth adjustment ratios for 2015 are 0.85 for mortality endpoints and 0.84 for morbidity endpoints. Mortality accounts for 93 percent of total health benefits and morbidity accounts for 7 percent of health benefits. Combining these elements with the total Base estimate of PM health benefits in 2030 of $89.8 billion , total PM health benefits in 2010 for the proposed standards are calculated as:

Total PM health benefits (2010) =

$89.8 billion * 0.203*(0.0002*0.876+0.194*0.961+0.806*0.552)*(0.93*.855+0.07*.838) = $9.8 billion

In order to develop the time stream of visibility benefits, we need to develop scaling factors based on the contribution of each emission species to light extinction. Similar to ambient $PM_{2.5}$, because we have only two estimates of the change in light extinction (2020 and 2030), we assume a very simple linear function for each species over time (assuming that the marginal contribution of each emission species to light extinction is independent of the other emission species) assuming that changes in the sulfate component of light extinction are associated with SO_2 emission reductions, changes in the nitrate component of light extinction are primarily associated with NOx emission reductions, and changes in the primary PM components of light extinction are associated with direct PM emission reductions. Linear relationships (slope and intercept) are calculated for each Class I area.

Using the linear relationships, we estimate the marginal contribution of SO_2, NOx, and direct PM to the change in light extinction at each Class I area in each year. Again, note that these estimates assume that the change in the relative effectiveness of each emission species in reducing light extinction that is observed between 2020 and 2030 can be extrapolated to other years.

Multiplying the year specific marginal contribution estimates by the appropriate emissions reductions in each year yields estimates of the changes in light extinction components, which are summed to obtain year specific changes in total light extinction. Benefits for each park in each specific year are then developed by scaling total benefits in a base year using the ratio of the change in light extinction in the target year to the base year, with additional scaling factors to account for growth in total population, and growth in per capita income. Total national visibility benefits for each year are obtained by summing the scaled benefits across Class I areas.

Table 9-16 provides undiscounted estimates of the time stream of benefits for the proposed standards for the Base and Alternative estimates using 3 and 7 percent concurrent discount rates[G]. Figure 9-1 shows the undiscounted time stream for the Base estimate using a 3 percent concurrent discount rate. Because of the assumptions we made about the linearity of benefits for each emission species, overall benefits are also linear, reflecting the relatively linear emissions reductions over time for each emission type. The exception is during the early years of the program, where there is little NOx emission reduction, so that benefits are dominated by SO_2 and direct $PM_{2.5}$ reductions.

Using a 3 percent intertemporal discount rate, the present value in 2004 of the benefits of the proposed standards for the base estimate is approximately $550 billion for the time period 2007 to 2030, using either a 3 percent concurrent discount rate or $520 billion using a 7 percent concurrent discount rate. For the alternative estimate, the present value using a 3 percent intertemporal discount rate is approximately $90 billion using either a 3 or 7 percent concurrent discount rate. Annualized benefits using a 3 percent intertemporal discount rate for the base estimate are approximately $30 billion using either a 3 or 7 percent concurrent discount rate. Annualized benefits using a 3 percent intertemporal discount rate for the alternative estimate are approximately $5 billion using either a 3 or 7 percent concurrent discount rate.

Using a 7 percent intertemporal discount rate, the present value in 2004 of the benefits of the proposed standards for the base estimate is approximately $290 billion for the time period 2007 to 2030, using a 3 percent concurrent discount rate or $270 billion using a 7 percent concurrent discount rate. For the alternative estimate, the present value using a 7 percent intertemporal discount rate is approximately $45 billion using a 3 percent concurrent discount rate or $48 billion using a 7 percent concurrent discount rate.

[G] We refer to discounting that occurs during the calculation of benefits for individual years as concurrent discounting. This is distinct from discounting that occurs over the time stream of benefits, which is referred to as intertemporal discounting.

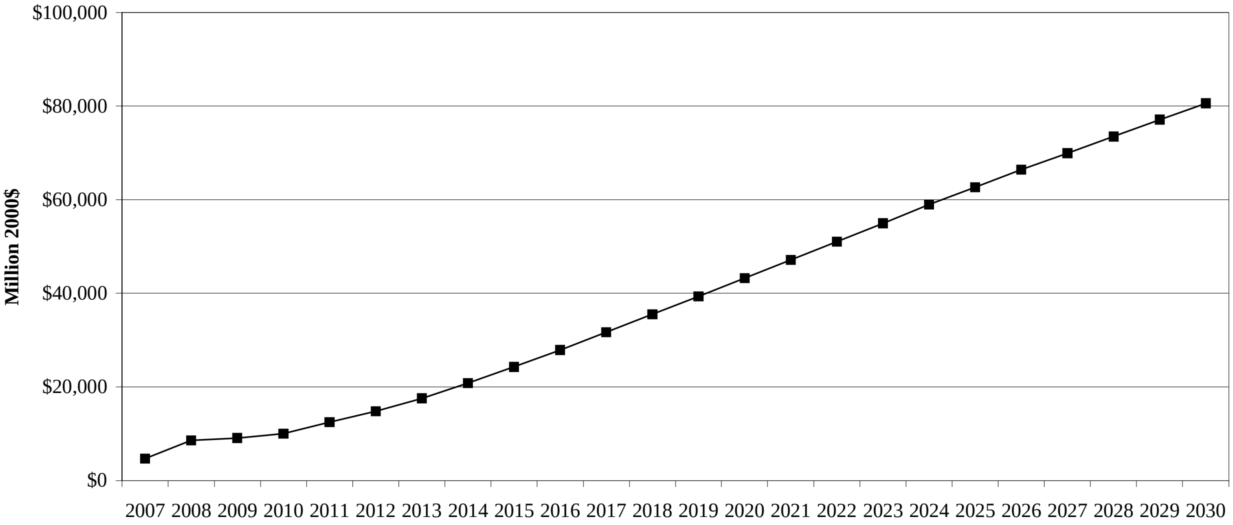
Table 9-16. Time Stream of Benefits for Proposed Nonroad Diesel Engine Standards[A,B]

Year	Base Estimate (Million 2000$)		Alternative Estimate (Million 2000$)	
	3% Concurrent Discount Rate	7% Concurrent Discount Rate	3% Concurrent Discount Rate	7% Concurrent Discount Rate
2007	$4,700	$4,400	$950	$1,000
2008	$8,600	$7,900	$1,800	$1,900
2009	$9,100	$8,400	$1,800	$2,000
2010	$10,000	$9,300	$2,000	$2,200
2011	$12,500	$11,500	$2,600	$2,700
2012	$14,800	$13,600	$3,100	$3,300
2013	$17,600	$16,200	$3,600	$3,900
2014	$20,800	$19,200	$4,300	$4,600
2015	$24,300	$22,400	$5,000	$5,300
2016	$27,900	$25,800	$5,700	$6,100
2017	$31,700	$29,200	$6,500	$6,900
2018	$35,500	$32,700	$7,200	$7,800
2019	$39,300	$36,300	$8,000	$8,600
2020	$43,200	$39,900	$8,800	$9,400
2021	$47,100	$43,500	$9,600	$10,000
2022	$51,000	$47,100	$10,000	$11,000
2023	$55,000	$50,700	$11,000	$12,000
2024	$58,900	$54,400	$12,000	$13,000
2025	$62,700	$57,800	$13,000	$14,000
2026	$66,400	$61,200	$13,000	$14,000
2027	$69,900	$64,600	$14,000	$15,000
2028	$73,500	$67,900	$15,000	$16,000
2029	$77,100	$71,200	$15,000	$17,000
2030	$80,600	$74,500	$16,000	$17,000
Present Value in 2004				
3% Intertemporal Discount Rate	$550,000	$510,000	$110,000	$120,000
7% Intertemporal Discount Rate	$290,000	$270,000	$58,000	$63,000

[A] All dollar estimates rounded to two significant digits.

[B] Results reflect the use of two different discount rates; a 3% rate which is recommended by EPA's Guidelines for Preparing Economic Analyses (US EPA, 2000c), and 7% which is recommended by OMB Circular A-94 (OMB, 1992).

Figure 9-1.
Base Estimate of the Stream of Annual Benefits for the Proposed Nonroad Diesel Engine Standards: 2007 to 2030



9.6 Comparison of Costs and Benefits

The estimated social cost (measured as changes in consumer and producer surplus) in 2030 to implement the final rule, as described in Chapter 8 is $1.5 billion (2000$). Thus, the net benefit (social benefits minus social costs) of the program at full implementation is approximately $79 + B billion, where B represents the sum of all unquantified benefits and disbenefits. In 2020, partial implementation of the program yields net benefits of $42 + B billion. Therefore, implementation of the proposed rule is expected, based purely on economic efficiency criteria, to provide society with a significant net gain in social welfare. Table 9-17 presents a summary of the benefits, costs, and net benefits of the proposed rule. Figure 9-2 displays the stream of benefits, costs, and net benefits of the Nonroad Diesel Engine and Fuel Standards from 2007 to 2030. In addition, Table 9-18 presents the present value of the stream of benefits, costs, and net benefits associated with the rule for this 23 year period (using a three percent discount rate). The total present value of the stream of monetized net benefits (benefits minus costs) is $540 billion.

Table 9-17.
Summary of Monetized Benefits, Costs, and Net Benefits of the Proposed Nonroad Diesel Engine and Fuel Standards[A]

	Base Estimate[B]	
	2020 (Billions of 2000 dollars)	**2030** (Billions of 2000 dollars)
Social Costs[C]	$1.4	$1.5
Social Benefits[D,E]:		
CO, VOC, Air Toxic-related benefits	Not monetized	Not monetized
Ozone-related benefits	Not monetized	Not monetized
PM-related Welfare benefits	$1.2	$1.9
PM-related Health benefits	$42 + B	$79 + B
Net Benefits (Benefits-Costs)[D,E]	$42 + B	$79 + B

[A] All costs and benefits are rounded to two significant digits.

[B] Base Estimate reflects premature mortality based on application of concentration-response function derived from long-term exposure to $PM_{2.5}$, valuation using the value of statistical lives saved apporach, and a willingness-to-pay approach for valuing chronic bronchitis incidence.

[C] Note that costs are the total costs of reducing all pollutants, including CO, VOCs and air toxics, as well as NOx and PM. Benefits in this table are associated only with PM, NOx and SO_2 reductions.

[D] Not all possible benefits or disbenefits are quantified and monetized in this analysis. Potential benefit categories that have not been quantified and monetized are listed in Table 9-1. B is the sum of all unquantified benefits and disbenefits.

[E] Monetized benefits are presented using two different discount rates. Results calculated using 3 percent discount rate are recommended by EPA’s *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000c). Results calculated using 7 percent discount rate are recommended by OMB Circular A-94 (OMB, 1992).

Figure 9-2.
Stream of Benefits, Costs, and Net Benefits of the
Proposed Nonroad Diesel Engine and Fuel Standards

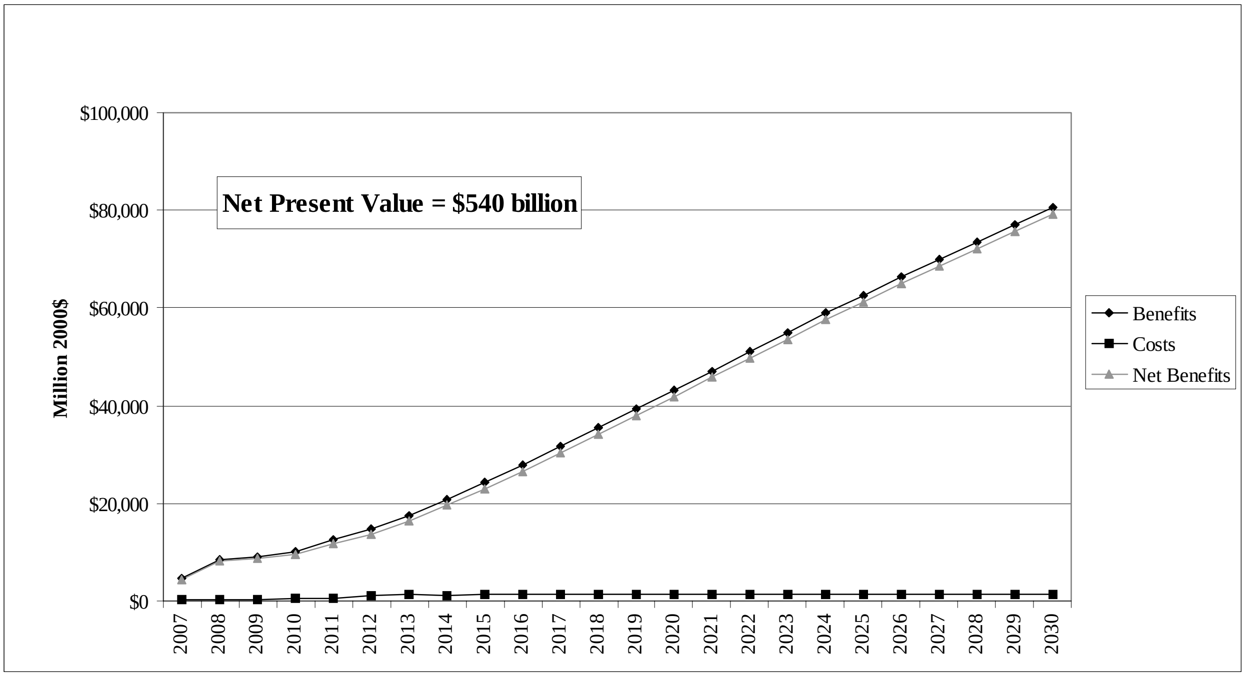


Table 9-18.
Present Value in 2004 of the Stream of Benefits, Costs, and Net Benefits for the Proposed Nonroad Diesel Engine and Fuel Standards
(Billions of 2000$)[a]

	Base
Social Costs	$17
Social Benefits	$550
Net Benefits	$530

[a] Rounded to two significant digits

Two key inputs to our benefit-cost analysis are the social costs and emission reductions associated with the proposed program. Each of these elements also has associated uncertainty which contributes to the overall uncertainty in our analysis of benefit-cost.

EPA engineering cost estimates are based upon considerable expertise and experience within the Agency. At the same time, any estimate of the future cost of control technology for engines or the cost of removing sulfur from diesel fuel is inherently uncertain to some degree. At the start is the question of what technology will actually be used to meet future standards, and what such technology will cost at the time of implementation. Our estimates of control costs are based upon current technology plus newer technology already “in the pipeline.” New technology not currently anticipated is by its nature not specifically included. Potential new production techniques which might lower costs are also not included in these estimates (although they are partially included among factors contributing to learning curve effects). On the other side of the equation are unforseen technical hurdles that may act to increase control system costs.

Some uncertainty is also introduced when translating engineering cost into social cost estimates. Our Economic Impact Assessment presented in Chapter 10 includes sensitivity analyses examining the effect of varying assumptions surrounding the following key factors (Chapter 10, Appendix 10-I):

- market supply and demand elasticity parameters
- alternative assumptions about the fuel market supply shifts and fuel maintenance savings
- alternative assumptions about the engine and equipment market supply shifts

For all of these factors, the change in social cost was projected to be very small, with a maximum impact of less than one percent.

Overall, we have limited means available to develop quantitative estimates of total uncertainty in costs. Some of the factors identified above can act to either increase or decrease actual cost compared to our estimates. Some, such as new technology developments and new production techniques, will act to lower costs compared to our estimates.

One source of a useful information about the overall uncertainty we might expect to see in cost is literature comparing historical rulemaking cost estimates with actual price increases when new standards went into effect.[H] Perhaps the most relevant of such studies is the paper by Anderson and Sherwood analyzing these effects for those mobile source rules adopted since the Clean Air Act Amendments of 1990. That paper reviewed six fuel quality rules and ten light-duty vehicle control rules that had been required by those amendments. It found that EPA estimates of the costs for future standards tended to be similar to or higher than actual price

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[H] For this proposal, we based our cost estimates on information received from industry and technical reports relevant to the US market. We are also aware of two studies done to support nonroad standards development in Europe, namely the VTT report and the EMA/Euromot report. We are not utilizing the cost information in these reports because neither one has sufficient information to allow us to understand or derive the relevant cost figures and therefore provide us information that could be used in trying to estimate cost uncertainty for nonroad diesel engine technologies.

changes observed in the market place. Table 9-19 presents a summary of results for the fuel and vehicle rules reviewed in the paper.

Table 9-19.
Comparison of Historical EPA Cost Estimates with Actual Price Changes

EPA Rule	EPA Mid-point Estimate	Actual Price Change	Percent Difference for Price vs EPA
Phase 2 RVP control	1.1 c/gal	0.5 c/gal	-54%
Reformulated Gasoline Phase 1	4.1 c/gal	2.2 c/gal	-46%
Reformulated Gasoline Phase 2	5.7 c/gal	5.1 c/gal	-10%
500ppm Sulfur Highway Diesel Fuel	2.2 c/gal	2.2 c/gal	0%
1994-2001 LDV Regulations	$446/vehicle	$347	-22%

The data in Table 9-19 would lead us to believe that cost uncertainty is largely a risk of overestimation by EPA. However, given the uncertainty in constructing the comparison in Anderson and Sherwood plus the increasing sophistication of our cost analyses as time goes on, we believe that a more conservative approach is appropriate. As a sensitivity factor for social cost variability we have chosen to evaluate a range of possible errors in social cost of from twenty percent higher to twenty percent lower than the EPA estimate. The resulting social cost range is shown in Table 9 -20. This uncertainty has virtually no impact on our estimates of the net benefits of the proposed rule, given the large magnitude by which benefits exceed costs.

Table 9-20.
Estimated Uncertainty for Social Cost of Proposal

Year	Social Cost Estimate	Uncertainty Range (-20 to +20 percent)
2010	$0.26 billion	$0.21 - $0.31 billion
2020	$1.4 billion	$1.1 - $1.6 billion
2030	$1.5 billion	$1.2 - $1.8 billion

Turning to the question of emissions uncertainty, the Agency does not at this time have useful quantitative information to bring to bear on this question. For our estimates, we rely on the best information that is available to us. However, there is uncertainty involved in many aspects of emissions estimations. Uncertainty exists in the estimates of emissions from the nonroad sources affected by this proposal, as well as in the universe of other sources included in the emission inventories used for our air quality modeling. To the extent that these other sources are unchanged between our baseline and control case, the impact of uncertainty in those estimates is lessened. Similarly, since the key driver of the benefits of our proposal is the changes produced by the new standards, the effect of uncertainty in the overall estimates of nonroad emissions on our benefits estimates may be lessened.

The main sources of uncertainty in our estimates of nonroad emissions fall in the three areas of population size estimates, equipment usage rates (activity) and engine emission factors. Since nonroad equipment is not subject to state registration and licensing requirements like those applying to highway vehicles, it is difficult to develop precise equipment counts for in-use nonroad equipment. Our modeled equipment populations are derived from related data about sales and scrappage rates. Similarly, annual amount of usage and related load factor information is estimated with some degree of uncertainty. We have access to extensive bodies of data on these areas, but are also aware of the need for improvement. Finally, the emission rates of engines in actual field operation cannot readily be measured at the present time, but are estimated from laboratory testing under a variety of typical operating cycles. While laboratory estimates are a reliable source of emissions data, they cannot fully capture all of the impacts of real in-use operation on emissions, leading to some uncertainty about the results. For further details on our modeling of nonroad emissions, please refer to the discussions in Chapter 3 of this RIA.

We have ongoing efforts in all three of these areas designed to improve their accuracy. Since the opportunity to gather better data exists, we have chosen to focus our main efforts on developing improved estimates rather than on developing elaborate techniques to estimate the uncertainty of current estimates. In the long run, better estimates are the most desired outcome.

One of the most important new tools we are developing is the use of portable emission measurement devices to gather detailed data on actual engines and equipment in daily use. These devices have recently become practical due to advances in computing and sensor technology, and will allow us to generate intensive data defining both activity-related factors (e.g., hours of use, load factors, patterns of use) and in-use emissions data specific to the measured activity and including effects from such things as age and emissions related deterioration. The Agency is pursuing this equipment for improving both its highway and nonroad engine emissions models.

Because of the multiplicity of factors involved, we cannot make a quantitative estimate of the uncertainty in our emissions estimates. In an attempt to estimate the effect of a reasonable amount of uncertainty, we have performed an analysis of the effect of a plus or minus five percent change in the amount of emission reduction produced by our proposal. Table 9-21 presents the results of this analysis for 2030 (where the largest effect would be seen).

Table 9-21.
Estimated Effect of Emissions Uncertainty on 2030 Benefits Estimates

Case Examined	Range of 2030 Benefit
-5% - +5% for NOx	\$80 - \$81 billion
-5% to + 5% for SO_2	\$80 - \$81 billion
-5% to +5% for PM	\$78 - \$83 billion
-5% to +5% for all emissions	\$76 - \$85 billion

The effect of this analysis shows the final benefit value changing a maximum of the full five percent sensitivity to a value of less than one percent, depending on which pollutant or pollutants were affected. In the real world, each of these three pollutants would not necessarily have the same uncertainty or see errors in the same direction at the same time.

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This appendix details the models and methods used to generate the benefits estimates from which the benefits of the proposed standards presented in Chapter IX are derived. This analysis uses a methodology generally consistent with benefits analyses performed for the recent analysis of the Heavy Duty Engines/Diesel Fuel rulemaking (U.S. EPA, 2000a) and the proposed Clear Skies Act (U.S. EPA, 2002). The benefits analysis relies on three major modeling components:

1) Calculation of the impact that a set of preliminary fuel and engine standards would have on the nationwide inventories for NOx, non-methane hydrocarbons (NMHC), SO_2, and PM emissions in 2020 and 2030;

2) Air quality modeling for 2020 and 2030 to determine changes in ambient concentrations of ozone and particulate matter, reflecting baseline and post-control emissions inventories.

3) A benefits analysis to determine the changes in human health and welfare, both in terms of physical effects and monetary value, that result from the projected changes in ambient concentrations of various pollutants for the modeled standards.

Figure 9A.1 illustrates the major steps in the analysis. Given baseline and post-control emissions inventories for the emission species expected to impact ambient air quality, we use sophisticated photochemical air quality models to estimate baseline and post-control ambient concentrations of ozone and PM, and deposition of nitrogen and sulfur for each year. The estimated changes in ambient concentrations are then combined with monitoring data to estimate population level exposures to changes in ambient concentrations for use in estimating health effects. Modeled changes in ambient data are also used to estimate changes in visibility, and changes in other air quality statistics that are necessary to estimate welfare effects. Changes in population exposure to ambient air pollution are then input to concentration-response functions to generate changes in incidence of health effects, or, changes in other exposure metrics are input to dose-response functions to generate changes in welfare effects. The resulting effects changes are then assigned monetary values, taking into account adjustments to values for growth in real income out to the year of analysis (values for health and welfare effects are in general positively related to real income levels). Finally, values for individual health and welfare effects are summed to obtain an estimate of the total monetary value of the changes in emissions.

On September 26, 2002, the National Academy of Sciences (NAS) released a report on its review of the Agency's methodology for analyzing the health benefits of measures taken to reduce air pollution. The report focused on EPA's approach for estimating the health benefits of regulations designed to reduce concentrations of airborne particulate matter (PM).

In its report, the NAS said that EPA has generally used a reasonable framework for analyzing the health benefits of PM-control measures. It recommended, however, that the

Agency take a number of steps to improve its benefits analysis. In particular, the NAS stated that the Agency should:

- include benefits estimates for a range of regulatory options;
- estimate benefits for intervals, such as every five years, rather than a single year;
- clearly state the projected baseline statistics used in estimating health benefits, including those for air emissions, air quality, and health outcomes;
- examine whether implementation of proposed regulations might cause unintended impacts on human health or the environment;
- when appropriate, use data from non-U.S. studies to broaden age ranges to which current estimates apply and to include more types of relevant health outcomes;
- begin to move the assessment of uncertainties from its ancillary analyses into its base analyses by conducting probabilistic, multiple-source uncertainty analyses. This assessment should be based on available data and expert judgment.

Although the NAS made a number of recommendations for improvement in EPA's approach, it found that the studies selected by EPA for use in its benefits analysis were generally reasonable choices. In particular, the NAS agreed with EPA's decision to use cohort studies to derive benefits estimates. It also concluded that the Agency's selection of the American Cancer Society (ACS) study for the evaluation of PM-related premature mortality was reasonable, although it noted the publication of new cohort studies that should be evaluated by the Agency.

EPA has addressed many of the NAS comments in our analysis of the proposed rule. We provide benefits estimates for each year over the rule implementation period for a wide range of regulatory alternatives, in addition to our proposed emission control program. We use the estimated time path of benefits and costs to calculate the net present value of benefits of the rule. In the RIA, we provide baseline statistics for air emissions, air quality, population, and health outcomes. We have examined how our benefits estimates might be impacted by expanding the age ranges to which epidemiological studies are applied, and we have added several new health endpoints, including non-fatal heart attacks, which are supported by both U.S. studies and studies conducted in Europe. We have also improved the documentation of our methods and provided additional details about model assumptions.

Several of the NAS recommendations addressed the issue of uncertainty and how the Agency can better analyze and communicate the uncertainties associated with its benefits assessments. In particular, the Committee expressed concern about the Agency's reliance on a single value from its analysis and suggested that EPA develop a probabilistic approach for analyzing the health benefits of proposed regulatory actions. The Agency agrees with this suggestion and is working to develop such an approach for use in future rulemakings. EPA plans to hold a meeting of its Science Advisory Board (SAB) in early Summer 2003 to review its plans for addressing uncertainty in its analyses. Our likely approach will incorporate short-term elements intended to provide interim methods in time for the final Nonroad rule to address uncertainty in important analytical parameters such as the concentration-response relationship for PM-related premature mortality. Our approach will also include longer-term elements intended to provide scientifically sound, peer-reviewed characterizations of the uncertainty surrounding a broader set of analytical parameters and assumptions, including but not limited to emissions and air quality modeling, demographic projections, population health status, concentration-response functions, and valuation estimates.

Our primary approach, generating our Base Estimate is a peer-reviewed method developed for previous risk and benefit-cost assessments carried out by the Environmental Protection Agency. It is the method used in the regulatory assessments of the Heavy Duty Diesel and Tier II (light duty engine) Rules and the Section 812 Report to Congress. Following the approach of these earlier assessments, along with the results of the Base Estimate, we present various sensitivity analyses on the Base Estimate that alter select subsets of variables, such as the concentration-response function for premature mortality.

Many of the techniques applied in analyzing the benefits of the proposed rule have also been reviewed by EPA's independent Science Advisory Board (SAB). We have relied heavily on the advice of the SAB in determining the health and welfare effects considered in the benefits analysis and in establishing the most scientifically valid measurement and valuation techniques. Since the publication of the final HD Engine/Diesel Fuel RIA, we have updated some of the assumptions and methods used in our analysis to reflect SAB and NAS recommendations, as well as advances in data and methods in air quality modeling, epidemiology, and economics. Changes to the methodology are described fully in the following sections and in the benefits technical support document (Abt Associates, 2003) and include the following:

- Demographic/population data:
  - We have updated our base population data from 1990 to Census 2000 block level data
  - We have developed future year population projections based on Woods and Poole Economics, Inc. 2001 Regional Projections of county population.
- Health effects incidence/prevalence data:
  - We have updated county-level mortality rates (all-cause, non-accidental, cardiopulmonary, lung cancer, COPD) from 1994-1996 to 1996-1998 using the CDC Wonder database.
  - We have updated hospitalization rates from 1994 to 1999 and switched from national rates to regional rates using 1999 National Hospital Discharge Survey results.
  - We have developed regional emergency room visit rates using results of the 2000 National Hospital Ambulatory Medical Care Survey.
  - We have updated prevalence of asthma and chronic bronchitis to 1999 using results of the National Health Interview Survey (HIS), as reported by the American Lung Association (ALA), 2002
  - We have developed non-fatal heart attack incidence rates based on National Hospital Discharge Survey results.
  - We have updated the national acute bronchitis incidence rate using HIS data as reported in ALA, 2002, Table 11.
  - We have updated the work loss days rate using the 1996 HIS data, as reported in Adams, et al. 1999, Table 41

  - We have developed school absence rates using data from the National Center for Education Statistics and the 1996 HIS, as reported in Adams, et al., 1999, Table 46.
  - We have developed baseline incidence rates for respiratory symptoms in asthmatics, based on epidemiological studies (Ostro et al. 2001; Vedal et al. 1998; Yu et al; 2000; McConnell et al., 1999; Pope et al., 1991).

- Concentration-Response Functions
  - We have added several new endpoints to the analysis, including
    > hospital admissions for all cardiovascular causes in adults 20-64, PM (Moolgavkar et al., 2000)
    > ER visits for asthma in children 0-18, PM (Norris et al., 1999)
    > non-fatal heart attacks, adults over 30, PM (Peters et al, 2001)
    > school loss days, Ozone (Gilliland et al, 2001; Chen et al, 2000)
    > hospital admissions for all respiratory causes in children under 2, Ozone (Burnett et al., 2001)
  - We have changed the sources for concentration-response functions for hospital admission for pneumonia, COPD, and total cardiovascular from Samet et al, 2000 (a PM_{10} study), to Lippmann et al, 2000 and Moolgavkar, 2000 ($PM_{2.5}$ studies)
  - We have added a separate table with incidence estimates for the asthmatic subpopulation, based on studies by Ostro et al, 2001; Yu et al, 2000; Vedal et al, 1998; Pope et al., 1991; Ostro et al., 1991; and McConnell et al., 1999.
  - We have added a separate table showing age specific impacts, as well as the impact of extending the population covered by a C-R function to additional ages, i.e. extending lower respiratory symptoms to all children, rather than only children aged 7-14.

- Valuation of Changes in Health Outcomes:
  - We have developed a value for school absence days by determining the proportion of families with two working families, multiplying that proportion by the number of school loss days, and multiplying the resulting number of school loss days resulting in a parent staying home (or requiring purchase of a caregivers time) by the average daily wage.
  - We have developed age-specific values for non-fatal heart attacks using cost-of-illness methods, based on direct cost estimates reported in Wittels et al (1990) and Russell et al (1998) and lost earnings estimates reported in Cropper and Krupnick (1990). These estimates include expected medical costs in the 5 years following a myocardial infarction, as well as the lost earnings over that period.
  - We have corrected a previous error in the valuation of acute bronchitis episodes. Previously, episodes were valued as if they lasted only a single day. We have corrected this value to account for multiday duration of episodes.

- Air Quality:
  - PM air quality modeling results are used to develop adjustment factors which will be applied to ambient monitoring data to estimate future base and control ambient PM

levels (consistent with past practice for ozone modeling). This change is due to the recent availability of sufficient ambient $PM_{2.5}$ monitoring data.

- We have changed the ozone air quality model from the Urban Airshed Model to CAM-X, modeled using 30 episode days in 1995 for the Eastern U.S. and 19 episode days in 1996 for the Western U.S. (note that in the HD Engine/Diesel Fuel analysis, we did not use ozone modeling results for the Western U.S.). For both Eastern and Western domains, a nested grid structure was used, with a 36 km outer resolution, and a 12 km inner resolution over urban areas.
- We have updated the PM air quality model, REMSAD, to version 7.3, run at 36 km grid resolution.

In addition to the above changes, for the proposed rule, the Agency has used an interim approach that shows the impact of several important alternative assumptions about the estimation and valuation of reductions in premature mortality and chronic bronchitis. This approach, which was developed in the context of the Agency's Clear Skies analysis, provides an alternative estimate of health benefits using the time series studies in place of cohort studies, as well as alternative valuation methods for mortality and chronic bronchitis risk reductions.

All such benefit estimates are subject to a number of assumptions and uncertainties, which are discussed throughout the appendix. For example key assumptions underlying the Base and Alternative Estimates for the mortality category include the following: (1) Inhalation of fine particles is causally associated with premature death at concentrations near those experienced by most Americans on a daily basis. While biological mechanisms for this effect have not yet been definitively established, the weight of the available epidemiological evidence supports an assumption of causality. (2) All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because fine particles directly emitted from diesel engines are chemically different from fine particles resulting from both utility sources and industrial facilities, but no clear scientific grounds exist for supporting differential effects estimates by particle type. (3) The concentration-response function for fine particles is approximately linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of particulate matter, including both regions that are in attainment with fine particle standard and those that do not meet the standard. (4) The forecasts for future emissions and associated air quality modeling are valid. Although recognizing the difficulties, assumptions and inherent uncertainties in the overall enterprise, these analyses are based on peer-reviewed scientific literature and up-to-date assessment tools, and we believe the results are highly useful in assessing this proposal.

In addition to the quantified and monetized benefits summarized above, there are a number of additional categories are not currently amenable to quantification or valuation. These include reduced acid and particulate deposition damage to cultural monuments and other materials; reduced ozone effects on forested ecosystems; and environmental benefits due to reductions of impacts of acidification in lakes and streams and eutrophication in coastal areas. Additionally, we have not quantified a number of known or suspected health effects linked with

PM and ozone for which appropriate concentration-response functions are not available or which do not provide easily interpretable outcomes (i.e. changes in forced expiratory volume (FEV1)). As a result, both the Base and Alternative monetized benefits may underestimate the total benefits attributable to the preliminary control options.

In general, the chapter is organized around the steps illustrated in Figure 9A.1. In section A, we describe and summarize the emissions inventories and modeled reductions in emissions of NOx, VOC, SO_2, and directly emitted diesel PM for the set of preliminary control options. In section B, we describe and summarize the air quality models and results, including both baseline and post-control conditions, and discuss the way modeled air quality changes are used in the benefits analysis. In Section C, we provide and overview of the data and methods that are used to quantify and value health and welfare endpoints, and provide a discussion of how we incorporate uncertainty into our analysis. In Section D, we report the results of the analysis for human health and welfare effects. Additional sensitivity analyses are provided in Appendix 9B.

Table 9A.1. Summary of Results: Estimated Benefits of the Modeled Preliminary Control Option

Estimation Method	Total Benefits[A, B] (Billions 2000$)	
	2020	2030
Base Estimate[C]:		
Using a 3% discount rate	$52+B	$92+B
Using a 7% discount rate	$49+B	$87+B
Alternative Estimate[D]:		
Using a 3% discount rate	$11+B	$19+B
Using a 7% discount rate	$11+B	$20+B

[A] Benefits of CO and HAP emission reductions are not quantified in this analysis and, therefore, are not presented in this table. The quantifiable benefits are from emission reductions of NOX, NMHC, SO_2 and PM only. For notational purposes, unquantified benefits are indicated with a "B" to represent the sum of additional monetary benefits and disbenefits. A detailed listing of unquantified health and welfare effects is provided in Table 9A-2.

[B] Results reflect the use of two different discount rates; a 3% rate which is recommended by EPA's Guidelines for Preparing Economic Analyses (US EPA, 2000c), and 7% which is recommended by OMB Circular A-94 (OMB, 1992). Results are rounded to two significant digits.

[C] Base Estimate reflects premature mortality based on application of concentration-response function derived from long-term exposure to $PM_{2.5}$, valuation using the value of statistical lives saved apporach, and a willingness-to-pay approach for valuing chronic bronchitis incidence.

[D] Alternative Estimate reflects premature mortality based on application of concentration-response function derived from short-term exposures to $PM_{2.5}$, valuation using the value of statistical life-years saved apporach, assumption of 0.5 life years saved for each COPD related premature mortality avoided and 5 years for all other causes of death, and a cost-of-illness approach for valuing chronic bronchitis incidence.

Figure 9A.1. Key Steps in Air Quality Modeling Based Benefits Analysis

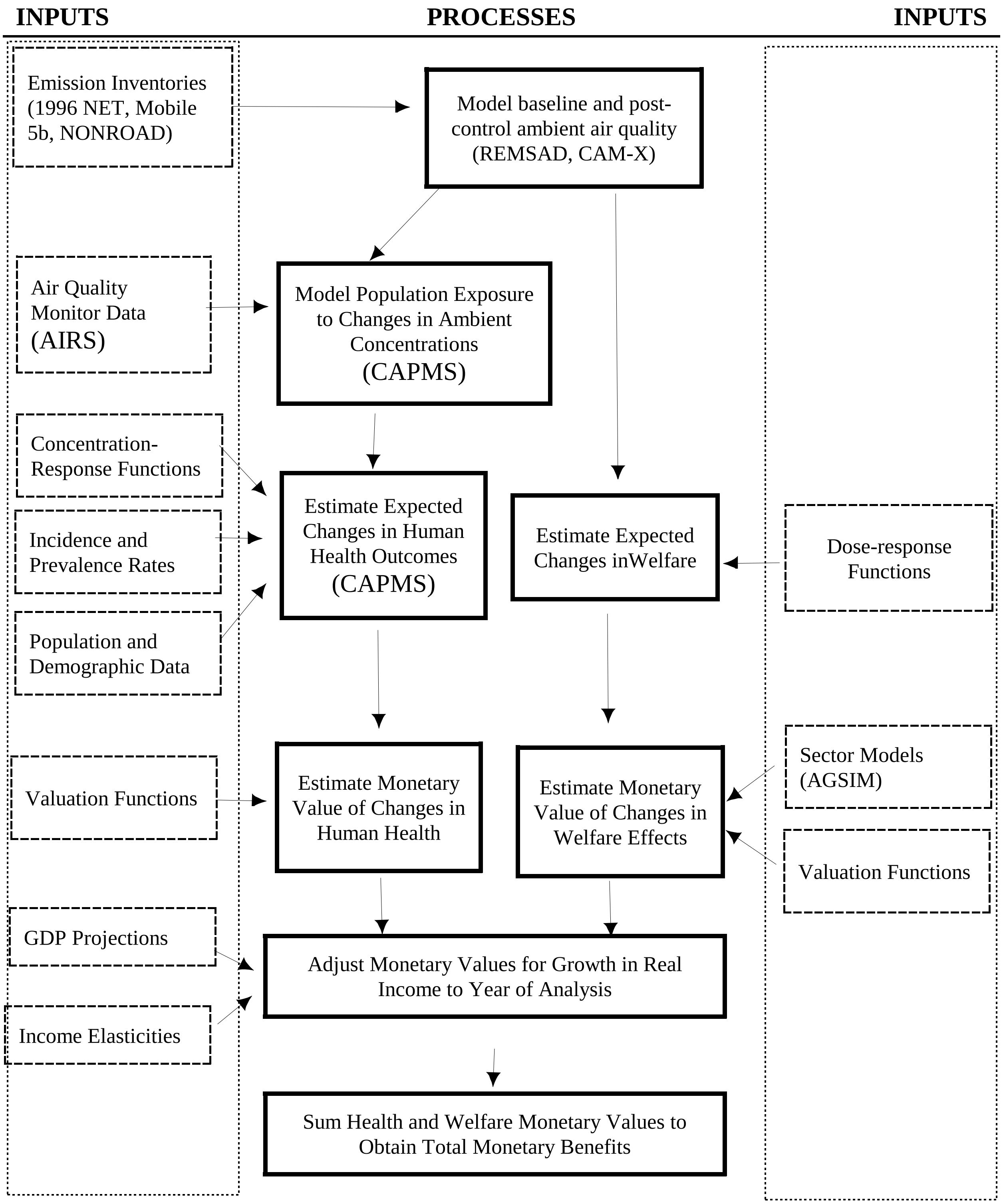


Table 9A.2.
Human Health and Welfare Effects of Pollutants Affected by the Proposed Nonroad Diesel Engine Rule

Pollutant/Effect	Quantified and Monetized in Base and Alternative Estimates[A]	Quantified and/or Monetized Effects in Sensitivity Analyses [B]	Unquantified Effects
Ozone/Health	Hospital admissions - respiratory Emergency room visits for asthma Minor restricted activity days School loss days	Chronic Asthma[C] Asthma attacks Cardiovascular emergency room visits Premature mortality – acute exposures[D] Acute respiratory symptoms	Increased airway responsiveness to stimuli Inflammation in the lung Chronic respiratory damage Premature aging of the lungs Acute inflammation and respiratory cell damage Increased susceptibility to respiratory infection Non-asthma respiratory emergency room visits
Ozone/Welfare	Decreased outdoor worker productivity Decreased yields for commercial crops (selected species) Decreased Eastern commercial forest productivity (selected species)		Decreased Western commercial forest productivity Decreased Eastern commercial forest productivity (other species) Decreased yields for fruits and vegetables Decreased yields for other commercial and non-commercial crops Damage to urban ornamental plants Impacts on recreational demand from damaged forest aesthetics Damage to ecosystem functions
PM/Health	Premature mortality – long term exposures Bronchitis - chronic and acute Hospital admissions - respiratory and cardiovascular Emergency room visits for asthma Non-fatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted activity days Work loss days	Premature mortality – short term exposures Asthma attacks (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Low birth weight Changes in pulmonary function Chronic respiratory diseases other than chronic bronchitis Morphological changes Altered host defense mechanisms Cancer Non-asthma respiratory emergency room visits

Pollutant/Effect	Quantified and Monetized in Base and Alternative Estimates[A]	Quantified and/or Monetized Effects in Sensitivity Analyses [B]	Unquantified Effects
PM/Welfare	Visibility in California, Southwestern, and Southeastern Class I areas	Visibility in Northeastern, Northwestern, and Midwestern Class I areas Visibility in residential and non-Class I areas Household soiling	
Nitrogen and Sulfate Deposition/ Welfare		Costs of nitrogen controls to reduce eutrophication in selected eastern estuaries	Impacts of acidic sulfate and nitrate deposition on commercial forests Impacts of acidic deposition on commercial freshwater fishing Impacts of acidic deposition on recreation in terrestrial ecosystems Impacts of nitrogen deposition on commercial fishing, agriculture, and forests Impacts of nitrogen deposition on recreation in estuarine ecosystems Reduced existence values for currently healthy ecosystems
SO_2/Health			Hospital admissions for respiratory and cardiac diseases Respiratory symptoms in asthmatics
NOX/Health			Lung irritation Lowered resistance to respiratory infection Hospital Admissions for respiratory and cardiac diseases
CO/Health			Premature mortality Behavioral effects Hospital admissions - respiratory, cardiovascular, and other Other cardiovascular effects Developmental effects Decreased time to onset of angina Non-asthma respiratory ER visits

Pollutant/Effect	Quantified and Monetized in Base and Alternative Estimates[A]	Quantified and/or Monetized Effects in Sensitivity Analyses [B]	Unquantified Effects
NMHCs [E] Health			Cancer (diesel PM, benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucous membranes (formaldehyde) Respiratory and respiratory tract Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation & congestion (acrolein)
NMHCs [E] Welfare			Direct toxic effects to animals Bioaccumlation in the food chain Reduction in odors

[A] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the Noroad Diesel Engine rule. See Section C-2 for a more complete discussion of presentation of benefits estimates.

[B] Alternative quantified and/or monetized effects are those presented as alternatives to the primary estimates or in addition to the primary estimates, but not included in the primary estimate of total monetized benefits.

[C] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, two epidemiological studies shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in exercising children and some non-smoking men (McConnell, 2002; McDonnell, et al., 1999).

[D] Premature mortality associated with ozone is not separately included in the primary analysis. It is assumed that the American Cancer Society (ACS)/ Krewski, et al., 2000 C-R function we use for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants (ACS/ Krewski, et al., 2000).

[E] All non-methane hydrocarbons (NMHCs) listed in the table are also hazardous air pollutants listed in the Clean Air Act.

9A.1 Summary of Emissions Inventories and Modeled Changes in Emissions from Nonroad Engines

For the preliminary control options we modeled, implementation will occur in two stages: reduction in sulfur content of nonroad diesel fuel and adoption of controls on new engines. Because full turnover of the fleet of nonroad diesel engines will not occur for many years, the emission reduction benefits of the proposed standards will not be fully realized until decades after the initial reduction in fuel sulfur content. Based on the projected time paths for emissions reductions, EPA chose to focus detailed emissions and air quality modeling on two future years, 2020 and 2030, which reflect partial and close to complete turnover of the fleet of nonroad diesel engines to models meeting the preliminary control options. Tables 9A-3 and 9A-4 summarize the baseline emissions of NO_X, SO_2, VOC, and direct diesel $PM_{2.5}$ and the change in the emissions from nonroad engines used in modeling air quality changes.

Emissions and air quality modeling decisions are made early in the analytical process. Since the preliminary control scenario was developed, EPA has gathered more information regarding the technical feasibility of the standards, and has revised the control scenario. Section 3.6 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary baseline and control scenarios used for the air quality modeling and the proposed baseline and control scenarios.

Chapter 3 discussed the development of the 1996, 2020 and 2030 baseline emissions inventories for the nonroad sector and for the sectors not affected by this proposed rule. The emission sources and the basis for current and future-year inventories are listed in Table 9A-5.

Table 9A-3
Summary of Baseline Emissions for Preliminary Nonroad Engine Control Options

	Pollutant Emissions (tons)			
Source	**NO_X**	**SO_2**	**VOC**	**$PM_{2.5}$**
1996 Baseline				
Nonroad Engines	1,583,641	172,175	221,398	178,500
All Other Sources	22,974,945	18,251,679	18,377,795	2,038,726
Total, All Sources	24,558,586	18,423,854	18,599,193	2,217,226
2020 Base Case				
Nonroad Engines	1,144,686	308,075	97,113	127,755
All Other Sources	14,394,399	14,882,962	13,812,619	1,940,307
Total, All Sources	15,539,085	15,191,037	13,909,732	2,068,062
2030 Base Case				
Nonroad Engines	1,231,981	360,933	97,345	143,185
All Other Sources	14,316,841	15,190,439	15,310,670	2,066,918
Total, All Sources	15,548,822	15,551,372	15,408,015	2,210,103

Table 9A-4
Summary of Emissions Changes for the Preliminary Nonroad Control Options*

	Pollutant			
Item	**NO_X**	**SO_2**	**VOC**	**$PM_{2.5}$**
2020 Nationwide Emission Changes				
Absolute Tons	663,618	304,735	23,172	91,278
Percent Reduction from Landbased Nonroad Emissions	58.0%	98.9%	23.9%	71.4%
Percentage Reduction from All Manmade Sources	4.5%	2.1%	0.2%	4.6%
2030 Emission Changes				
Absolute Tons	1,009,744	359,774	34,060	129,073
Percent Reduction from Landbased Nonroad Emissions	82.0%	99.7%	35.0%	90.0%
Percentage Reduction from All Manmade Sources	6.3%	2.1%	0.2%	5.5%

* Does not include SO_x and $PM_{2.5}$ reductions from recreational marine diesel engines, commercial marine diesel engines, and locomotives due to control of diesel fuel sulfur levels.

Table 9A-5
Emissions Sources and Basis for Current and Future-Year Inventories

Emissions Source	1996 Base year	Future-year Base Case Projections
Utilities	1996 NEI Version 3.12 (CEM data)	Integrated Planning Model (IPM)
Non-Utility Point and Area sources	1996 NEI Version 3.12 (point) Version 3.11 (area)	BEA growth projections
Highway vehicles	MOBILE5b model with MOBILE6 adjustment factors for VOC and NOX; PART5 model for PM	VMT projection data
Nonroad engines (except locomotives, commercial marine vessels, and aircraft)	NONROAD2002 model	BEA and Nonroad equipment growth projections

Note: Full description of data, models, and methods applied for emissions inventory development and modeling are provided in Emissions Inventory TSD (EPA, 2003a).

9A.2 Air Quality Impacts

This section summarizes the methods for and results of estimating air quality for the 2020 and 2030 base cases and control scenarios for the purposes of benefit-cost analyses. EPA has focused on the health, welfare, and ecological effects that have been linked to air quality changes. These air quality changes include the following:

- Ambient particulate matter (PM_{10} and $PM_{2.5}$)–as estimated using a national-scale version of the REgional Modeling System for Aerosols and Deposition (REMSAD);

- Ambient ozone–as estimated using regional-scale applications of the Comprehensive Air Quality Model with Extensions (CAMx); and

- Visibility degradation (i.e., regional haze), as developed using empirical estimates of light extinction coefficients and efficiencies in combination with REMSAD modeled reductions in pollutant concentrations.

Although we expect reductions in airborne sulfur and nitrogen deposition, these air quality impacts have not been quantified for this proposed rule nor have the associated benefits been estimated.

The air quality estimates in this section are based on the emission changes for the modeled preliminary control program discussed in Chapter 3. These air quality results are in turn associated with human populations and ecosystems to estimate changes in health and welfare effects. In Section B-1, we describe the estimation of PM air quality using REMSAD, and in Section B-2, we cover the estimation of ozone air quality using CAMx. Lastly, in Section B-3, we discuss the estimation of visibility degradation.

9A.2.1 PM Air Quality Estimates

We use the emissions inputs summarized above with a national-scale version of the REgional Model System for Aerosols and Deposition (REMSAD) to estimate PM air quality in the contiguous U.S. REMSAD is a three-dimensional grid-based Eulerian air quality model designed to estimate annual particulate concentrations and deposition over large spatial scales (e.g., over the contiguous U.S.). Consideration of the different processes that affect primary (directly emitted) and secondary (formed by atmospheric processes) PM at the regional scale in different locations is fundamental to understanding and assessing the effects of proposed pollution control measures that affect ozone, PM and deposition of pollutants to the surface.[a] Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, REMSAD is useful for evaluating the impacts of the proposed rule on U.S. PM concentrations.

REMSAD was peer-reviewed in 1999 for EPA as reported in *"Scientific Peer-Review of the Regulatory Modeling System for Aerosols and Deposition*" (Seigneur et al., 1999). Earlier versions of REMSAD have been employed for the EPA's Prospective 812 Report to Congress, EPA's HD Engine/Diesel Fuel rule, and EPA's air quality assessment of the Clear Skies Initiative. Version 7 of REMSAD was employed for this analysis and is fully described in the air quality modeling technical support document (US EPA, 2003b). This version reflects updates in the following areas to improve performance and address comments from the 1999 peer-review:

- Gas phase chemistry updates to "micro-CB4" mechanism including new treatment for the NO3 and N2O5 species and the addition of several reactions to better account for the wide ranges in temperature, pressure, and concentrations that are encountered for regional and national applications.

- PM chemistry updates to calculate particulate nitrate concentrations through use of the MARS-A equilibrium algorithm and internal calculation of secondary organic aerosols from both biogenic (terpene) and anthropogenic (estimated aromatic) VOC emissions.

[A] Given the potential impact of the Nonroad Engine/Diesel Fuel rule on secondarily formed particles it is important to employ a Eulerian model such as REMSAD. The impact of secondarily formed pollutants typically involves primary precursor emissions from a multitude of widely dispersed sources, and chemical and physical processes of pollutants that are best addressed using an air quality model that employs an Eulerian grid model design.

- Aqueous phase chemistry updates to incorporate the oxidation of SO_2 by O3 and O2 and to include the cloud and rain liquid water content from MM5 meteorological data directly in sulfate production and deposition calculations.

As discussed earlier in Chapter 2, the model tends to underestimate observed $PM_{2.5}$ concentrations nationwide, especially over the western U.S.

Our analysis applies the modeling system to the entire U.S. for the five emissions scenarios: a 1996 baseline projection, a 2020 baseline projection and a 2020 projection with nonroad controls, a 2030 baseline projection and a 2030 projection with nonroad controls. As discussed in the Benefits Analysis TSD, we use the relative predictions from the model by combining the 1996 base-year and each future-year scenario with ambient air quality observations to determine the expected change in 2020 or 2030 ozone concentrations due to the rule (Abt Associates, 2003). These results are used solely in the benefits analysis.

REMSAD simulates every hour of every day of the year and, thus, requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, 1-hour average emissions estimates and meteorological fields, initial and boundary conditions, and land-use information. As applied to the contiguous U.S., the model segments the area within the region into square blocks called grids (roughly equal in size to counties), each of which has several layers of air conditions. Using this data, REMSAD generates predictions of 1-hour average PM concentrations for every grid. We then calibrate the modeling results to develop 2020 and 2030 PM estimates at monitor sites by normalizing the observations to the observed 1996 concentrations at each monitor site. For areas (grids) without PM monitoring data, we interpolated concentration values using data from monitors surrounding the area. After completing this process, we then calculated daily and seasonal PM air quality metrics as inputs to the health and welfare C-R functions of the benefits analysis. The following sections provide a more detailed discussion of each of the steps in this evaluation and a summary of the results.

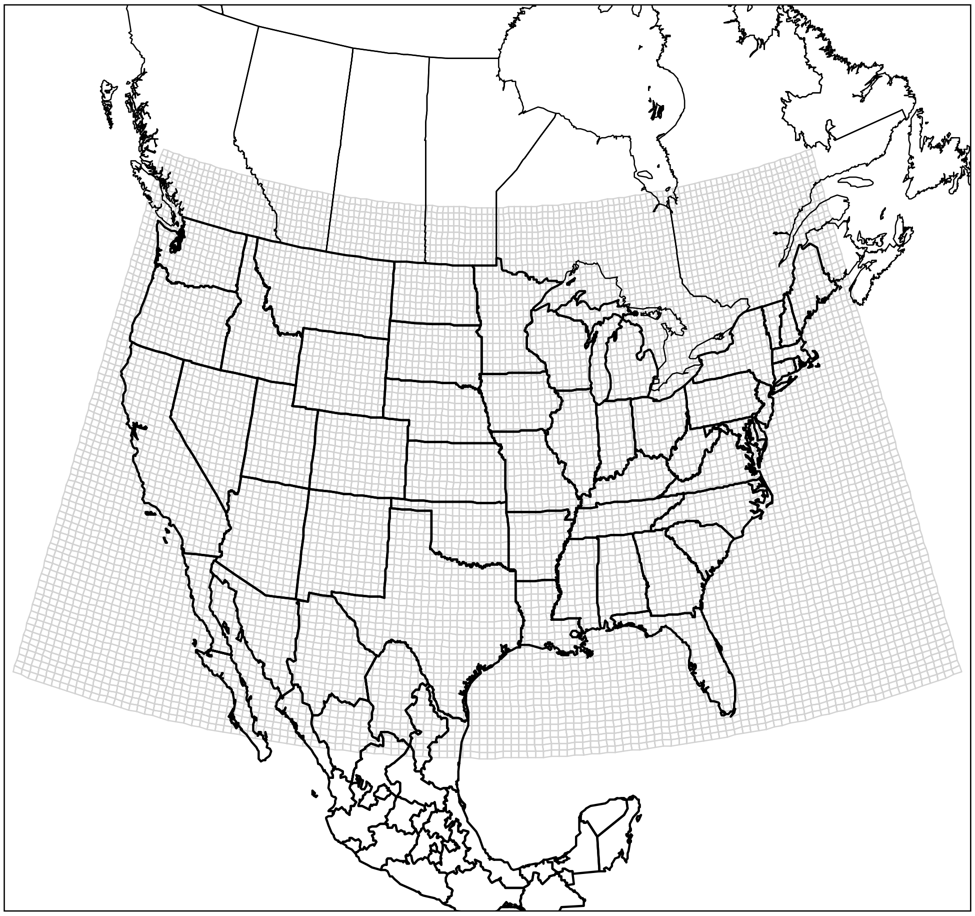
9A.2.1.1 Modeling Domain

The PM air quality analyses employed the modeling domain used previously in support of Clear Skies air quality assessment. As shown in Figure 9A-2, the modeling domain encompasses the lower 48 States and extends from 126 degrees to 66 degrees west longitude and from 24 degrees north latitude to 52 degrees north latitude. The model contains horizontal grid-cells across the model domain of roughly 36 km by 36 km. There are 12 vertical layers of atmospheric conditions with the top of the modeling domain at 16,200 meters. The 36 by 36 km horizontal grid results in a 120 by 84 grid (or 10,080 grid-cells) for each vertical layer. Figure 9A-3 illustrates the horizontal grid-cells for Maryland and surrounding areas.

9A.2.1.2 Simulation Periods

For use in this benefits analysis, the simulation periods modeled by REMSAD included separate full-year application for each of the five emissions scenarios as described in Chapter 3, i.e., 1996 baseline and the 2020 and 2030 base cases and control scenarios.

Figure 9A-2
REMSAD Modeling Domain for Continental United States



Note: Gray markings define individual grid-cells in the REMSAD model.

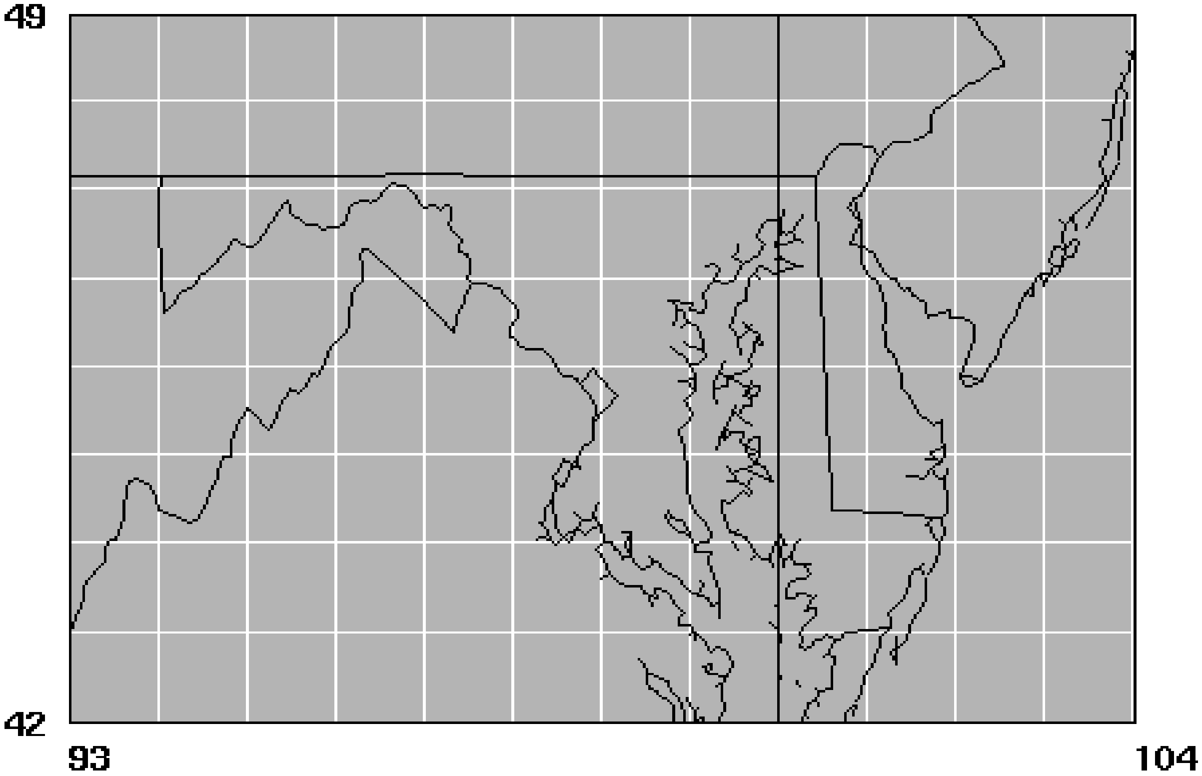


Figure 9A-3. Example of REMSAD 36 x 36km Grid-cells for Maryland Area

9A.2.1.3 Model Inputs

REMSAD requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, 1-hour average emissions estimates and meteorological fields, initial and boundary conditions, and land-use information. Separate emissions inventories were prepared for the 1996 baseline and each of the future-year base cases and control scenarios. All other inputs were specified for the 1996 baseline model application and remained unchanged for each future-year modeling scenario.

Similar to CAMx, REMSAD requires detailed emissions inventories containing temporally allocated emissions for each grid-cell in the modeling domain for each species being simulated. The previously described annual emission inventories were preprocessed into model-ready inputs through the SMOKE emissions preprocessing system. Details of the preprocessing of emissions through SMOKE as provided in the emissions modeling TSD. Meteorological inputs reflecting 1996 conditions across the contiguous U.S. were derived from Version 5 of the Mesoscale Model (MM5). These inputs included horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer. Details of the annual 1996 MM5 modeling are provided in Olerud (2000).

Initial species concentrations and lateral boundary conditions were specified to approximate background concentrations of the species; for the lateral boundaries the concentrations varied (decreased parabolically) with height. These background concentrations are provided in the air quality modeling TSD (U.S. EPA, 2003b). Land use information was obtained from the U.S. Geological Survey database at 10 km resolution and aggregated to the ~36 KM horizontal resolution used for this REMSAD application.

9A.2.1.4 Converting REMSAD Outputs to Benefits Inputs

REMSAD generates predictions of hourly PM concentrations for every grid. The particulate matter species modeled by REMSAD include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (e.g., sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily-formed particles. These hourly predictions for each REMSAD grid-cell are aggregated to daily averages and used in conjunction with observed PM concentrations from AIRS to generate the predicted changes in the daily and annual PM air quality metrics (i.e., annual mean PM concentration) from the future-year base case to future-year control scenario as inputs to the health and welfare C-R functions of the benefits analysis.[b] In addition, the speciated predictions from REMSAD are employed as inputs to a post-processing module that estimates atmospheric visibility, as discussed later in Section 9A.3.

[B] Based on AIRS, there were 1,071 FRM PM monitors with valid data as defined as more than 11 observations per season.

In order to estimate PM-related health and welfare effects for the contiguous U.S., daily and annual average PM concentrations are required for every location. Given available PM monitoring data, we generated an annual profile for each location in the contiguous 48 States in two steps: (1) we combine monitored observations and modeled PM predictions to interpolate forecasted daily PM concentrations for each REMSAD grid-cell, and (2) we compute the daily and annual PM measures of interest based on the annual PM profiles. [c] These methods are described in detail in the benefits analysis technical support document (Abt Associates, 2003).

9A.2.1.5 PM Air Quality Results

Table 9A-5 provides a summary of the predicted ambient $PM_{2.5}$ concentrations for the 2020 and 2030 base cases and changes associated with Nonroad Engine/Diesel Fuel control scenarios. The REMSAD results indicate that the predicted change in PM concentrations is composed almost entirely of reductions in fine particulates ($PM_{2.5}$) with little or no reduction in coarse particles (PM_{10} less $PM_{2.5}$). Therefore, the observed changes in PM_{10} are composed primarily of changes in $PM_{2.5}$. In addition to the standard frequency statistics (e.g., minimum, maximum, average, median), Table 9A-5 provides the population-weighted average which better reflects the baseline levels and predicted changes for more populated areas of the nation. This measure, therefore, will better reflect the potential benefits of these predicted changes through exposure changes to these populations. As shown, the average annual mean concentrations of $PM_{2.5}$ across all U.S. grid-cells declines by roughly 2.5 percent (or 0.2 $\mu g/m^3$) and 3.4 percent (or 0.28 $\mu g/m^3$) in 2020 and 2030, respectively. The population-weighted average mean concentration declined by 3.3 percent (or 0.42 $\mu g/m^3$) in 2020 and 4.5 percent (or 0.59 $\mu g/m^3$) in 2030, which is much larger in absolute terms than the spatial average for both years. This indicates the proposed rule generates greater absolute air quality improvements in more populated, urban areas.

[C] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation (See Abt Associates (2003) for a more detailed description).

Table 9A-6.
Summary of Base Case PM Air Quality and Changes Due to Nonroad Engine/Diesel Fuel Standards: 2020 and 2030

Statistic	*2020*			*2030*		
	Base Case	*Change*[a]	*Percent Change*	*Base Case*	*Change*[a]	*Percent Change*
$PM_{2.5}$ ($\mu g/m^3$)						
Minimum Annual Mean [b]	2.18	-0.02	-0.78%	2.33	-0.02	-1.01%
Maximum Annual Mean [b]	29.85	-1.36	-4.56%	32.85	-2.03	-6.18%
Average Annual Mean	8.10	-0.20	-2.49%	8.37	-0.28	-3.38%
Median Annual Mean	7.50	-0.18	-2.68%	7.71	-0.22	-2.80%
Pop-Weighted Average Annual Mean [c]	12.42	-0.42	-3.34%	13.07	-0.59	-4.48%

[a] The change is defined as the control case value minus the base case value.

[b] The base case minimum (maximum) is the value for the populated grid-cell with the lowest (highest) annual average. The change relative to the base case is the observed change for the populated grid-cell with the lowest (highest) annual average in the base case.

[c] Calculated by summing the product of the projected REMSAD grid-cell population and the estimated PM concentration, for that grid-cell and then dividing by the total population in the 48 contiguous States.

Table 9A-6 provides information on the populations in 2020 and 2030 that will experience improved PM air quality. There are significant populations that live in areas with meaningful reductions in annual mean $PM_{2.5}$ concentrations resulting from the proposed rule. As shown, almost 10 percent of the 2030 U.S. population are predicted to experience reductions of greater than 1 $\mu g/m^3$. This is an increase from the 2.7 percent of the U.S. population that are expected to experience such reductions in 2020. Furthermore, just over 20 percent of the 2030 U.S. population will benefit from reductions in annual mean $PM_{2.5}$ concentrations of greater than 0.75 $\mu g/m^3$ and slightly over 50 percent will live in areas with reductions of greater than 0.5 $\mu g/m^3$. This information indicates how widespread the improvements in PM air quality are expected to be and the large populations that will benefit from these improvements.

Table 9A-7
Distribution of PM2.5 Air Quality Improvements Over Population Due to Nonroad Engine/Diesel Fuel Standards: 2020 and 2030

Change in Annual Mean $PM_{2.5}$ Concentrations ($\mu g/m^3$)	*2020 Population*		*2030 Population*	
	Number (millions)	*Percent (%)*	*Number (millions)*	*Percent (%)*
$0 > \Delta PM_{2.5}$ Conc ≤ 0.25	65.11	19.75%	28.60	8.04%
$0.25 > \Delta PM_{2.5}$ Conc ≤ 0.5	184.52	55.97%	147.09	41.33%
$0.5 > \Delta PM_{2.5}$ Conc ≤ 0.75	56.66	17.19%	107.47	30.20%
$0.75 > \Delta PM_{2.5}$ Conc ≤ 1.0	14.60	4.43%	38.50	10.82%
$1.0 > \Delta PM_{2.5}$ Conc ≤ 1.25	5.29	1.60%	88.22	2.48%
$1.25 > \Delta PM_{2.5}$ Conc ≤ 1.5	3.51	1.06%	15.52	4.36%
$1.5 > \Delta PM_{2.5}$ Conc ≤ 1.75	0	0.00%	5.70	1.60%
$\Delta PM_{2.5}$ Conc > 1.75	0	0.00%	4.19	1.18%

[a] The change is defined as the control case value minus the base case value.

Table 9A-7 provides additional insights on the changes in PM air quality resulting from the proposed standards. The information presented previously in Table 9A-5 illustrated the absolute and relative changes for different points along the distribution of baseline 2020 and 2030 $PM_{2.5}$ concentration levels, e.g., the change reflects the lowering of the minimum predicted baseline concentration rather than the minimum predicted change for 2020 and 2030. The latter is the focus of Table 9A-7 as it presents the distribution of predicted changes in both absolute terms (i.e., $\mu g/m^3$) and relative terms (i.e., percent) across individual REMSAD grid-cells. Therefore, it provide more information on the range of predicted changes associated with the proposed rule. As shown for 2020, the absolute reduction in annual mean $PM_{2.5}$ concentration ranged from a low of 0.02 $\mu g/m^3$ to a high of 1.36 $\mu g/m^3$, while the relative reduction ranged from a low of 0.3 percent to a high of 12.2 percent. Alternatively, for 2030, the absolute reduction ranged from 0.02 to 2.03 $\mu g/m^3$, while the relative reduction ranged from 0.4 to 15.5 percent.

Table 9A-8. Summary of Absolute and Relative Changes in PM Air Quality Due to Nonroad Engine/Diesel Fuel Standards: 2020 and 2030

	2020	*2030*
Statistic	*$PM_{2.5}$ Annual Mean*	*$PM_{2.5}$ Annual Mean*
Absolute Change from Base Case (µg/m^3)[a]		
Minimum	-0.02	-0.02
Maximum	-1.36	-2.03
Average	-0.20	-0.28
Median	-0.19	-0.26
Population-Weighted Average [c]	-0.42	-0.59
Relative Change from Base Case (%)[b]		
Minimum	-0.33%	-0.44%
Maximum	-12.24%	-15.52%
Average	-2.44%	-3.32%
Median	-2.33%	-3.13%
Population-Weighted Average [c]	-3.28%	-4.38%

[a] The absolute change is defined as the control case value minus the base case value for each REMSAD grid-cell.

[b] The relative change is defined as the absolute change divided by the base case value, or the percentage change, for each gridcell. The information reported in this section does not necessarily reflect the same gridcell as is portrayed in the absolute change section.

[c] Calculated by summing the product of the projected gridcell population and the estimated gridcell PM absolute/relative measure of change, and then dividing by the total population in the 48 contiguous states.

9A.2.2 Ozone Air Quality Estimates

We use the emissions inputs summarized in Section 9A.1 with a regional-scale version of CAMx to estimate ozone air quality in the Eastern and Western U.S. CAMx is an Eulerian three-dimensional photochemical grid air quality model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect ozone formation. Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the CAMx is useful for evaluating the impacts of the proposed rule on U.S. ozone concentrations. As discussed earlier in Chapter 2, although the model tends to underestimate observed ozone, especially over the western U.S., it exhibits less bias and error than any past regional ozone modeling application conducted by EPA (i.e., OTAG, On-highway Tier-2, and HD Engine/Diesel Fuel).

Our analysis applies the modeling system separately to the Eastern and Western U.S. for five emissions scenarios: a 1996 baseline projection, a 2020 baseline projection and a 2020 projection with nonroad controls, a 2030 baseline projection and a 2030 projection with nonroad controls. As discussed in the Benefits Analysis TSD, we use the relative predictions from the model by combining the 1996 base-year and each future-year scenario with ambient air quality observations to determine the expected change in 2020 or 2030 ozone concentrations due to the rule (Abt Associates, 2003). These results are used solely in the benefits analysis.

The CAMx modeling system requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, day-specific emissions estimates and meteorological fields, initial and boundary conditions, and land-use information. The model divides the continental United States into two regions: East and West. As applied to each region, the model segments the area within the subject region into square blocks called grids (roughly equal in size to counties), each of which has several layers of air conditions that are considered in the analysis. Using this data, the CAMx model generates predictions of hourly ozone concentrations for every grid. We then calibrate the results of this process to develop 2020 and 2030 ozone profiles at monitor sites by normalizing the observations to the observed ozone concentrations at each monitor site. For areas (grids) without ozone monitoring data, we interpolated ozone values using data from monitors surrounding the area. After completing this process, we calculated daily and seasonal ozone metrics to be used as inputs to the health and welfare C-R functions of the benefits analysis. The following sections provide a more detailed discussion of each of the steps in this evaluation and a summary of the results.

9A.2.2.1 Modeling Domain

The modeling domain representing the Eastern U.S. is the same as that used previously for OTAG and the On-highway Tier-2 rulemaking. As shown in Figure 9A-4, this domain encompasses most of the Eastern U.S. from the East coast to mid-Texas and consists of two grids with differing resolutions. The modeling domain extends from 99 degrees to 67 degrees west longitude and from 26 degrees to 47 degrees north latitude. The inner portion of the modeling domain shown in Figure 9A-4 uses a relatively fine grid of 12 km consisting of nine vertical layers. The outer area has less horizontal resolution, as it uses a 36 km grid with the same nine vertical layers. The vertical height of the modeling domain is 4,000 meters above ground level for both areas.

The modeling domain representing the Western U.S. is the same as that used previously for the On-highway Tier-2 rulemaking. As shown in Figure 9A-5, this domain encompasses the area west of the 99th degree longitude (which runs through North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas) and consists of two grids with differing resolutions. The domain extends from 127 degrees to 99 degrees west longitude and from 26 degrees to 52 degrees north latitude. The inner portion of the modeling domain shown in Figure 9A-5 uses a relatively fine grid of 12 km consisting of eleven vertical layers. The outer area has less horizontal resolution, as it uses a 36 km grid with the same eleven vertical layers. The vertical height of the modeling domain is 4,800 meters above ground level.

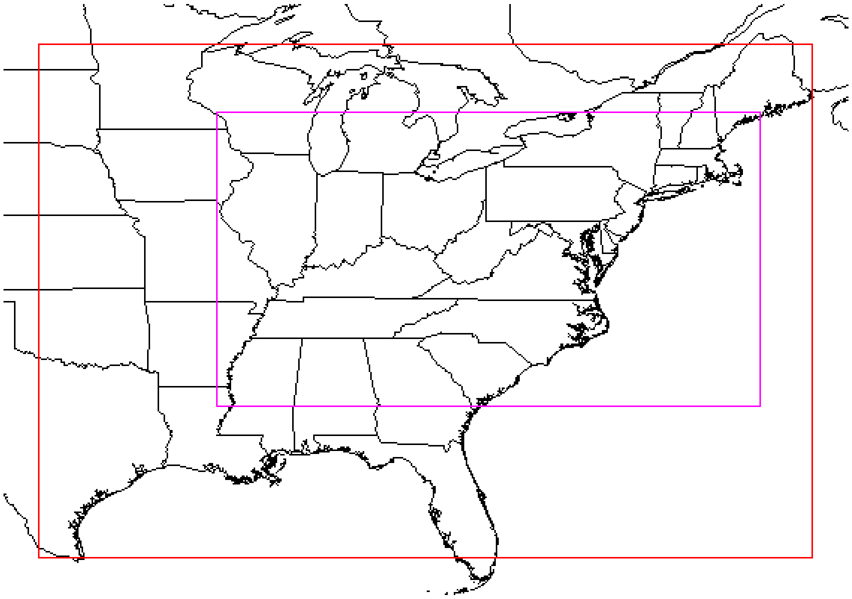


Figure 9A-4. CAMx Eastern U.S. Modeling Domain.

Note: The inner area represents fine grid modeling at 12 km resolution, while the outer area represents the coarse grid modeling at 36 km resolution.

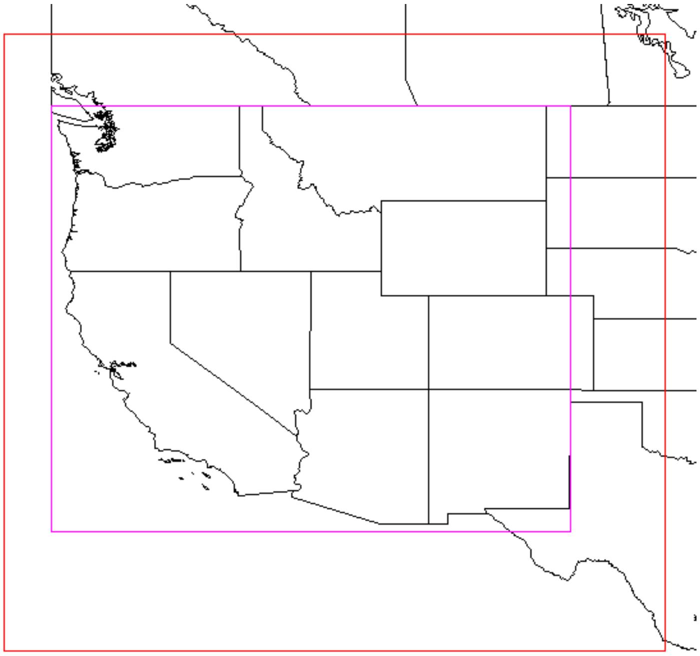


Figure 9A-5. CAMx Western U.S. Modeling Domain.

Note: The inner area represents fine grid modeling at 12 km resolution, while the outer area represents the coarse grid modeling at 36 km resolution.

9A.2.2.2 Simulation Periods

For use in this benefits analysis, the simulation periods modeled by CAMx included several multi-day periods when ambient measurements recorded high ozone concentrations. A simulation period, or episode, consists of meteorological data characterized over a block of days that are used as inputs to the air quality model. A simulation period is selected to characterize a variety of ozone conditions including some days with high ozone concentrations in one or more portions of the U.S. and observed exceedances of the 1-hour NAAQS for ozone being recorded at monitors. We focused on the summer of 1995 for selecting the episodes to model in the East and the summer of 1996 for selecting the episodes to model in the West because each is a recent time period for which we had model-ready meteorological inputs and this timeframe contained several periods of elevated ozone over the Eastern and Western U.S., respectively. As detailed in the air quality modeling TSD, this analysis used three multi-day meteorological scenarios during the summer of 1995 for the model simulations over the eastern U.S.: June 12-24, July 5-15, and August 7-21. Two multi-day meteorological scenarios during the summer of 1996 were used in the model simulations over the western U.S.: July 5-15 and July 18-31. Each of the five emissions scenarios (1996 base year, 2020 base, 2020 control, 2030 baseline, 2030 control) were simulated for the selected episodes. These episodes include a three day “ramp-up” period to initialize the model, but the results for these days are not used in this analysis.

9A.2.2.3 Converting CAMx Outputs to Full-Season Profiles for Benefits Analysis

This study extracted hourly, surface-layer ozone concentrations for each grid-cell from the standard CAMx output file containing hourly average ozone values. These model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[d,e] The predicted changes in ozone concentrations from the future-year base case to future-year control scenario serve as inputs to the health and welfare C-R functions of the benefits analysis, i.e., the Criteria Air Pollutant Modeling System (CAPMS).

In order to estimate ozone-related health and welfare effects for the contiguous U.S., full-season ozone data are required for every CAPMS grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in the contiguous 48 States in two steps: (1) we combine monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 8 km by 8 km population grid-cells, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the

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[D] The ozone season for this analysis is defined as the 5-month period from May to September; however, to estimate certain crop yield benefits, the modeling results were extended to include months outside the 5-month ozone season.

[E] Based on AIRS, there were 961 ozone monitors with sufficient data, i.e., 50 percent or more days reporting at least 9 hourly observations per day (8 am to 8 pm) during the ozone season.

daily average. [f,g] For the analysis of ozone impacts on agriculture and commercial forestry, we use a similar approach except air quality is interpolated to county centroids as opposed to population grid-cells. We report ozone concentrations as a cumulative index called the SUM06. The SUM06 is the sum of the ozone concentrations for every hour that exceeds 0.06 parts per million (ppm) within a 12-hour period from 8 am to 8 pm in the months of May to September. These methods are described in detail in the benefits analysis technical support document (Abt Associates, 2003).

9A.2.2.4 Ozone Air Quality Results

This section provides a summary the predicted ambient ozone concentrations from the CAMx model for the 2020 and 2030 base cases and changes associated with the Nonroad Engine/Diesel Fuel control scenario. In Tables 9A-8 and 9A-9, we provide those ozone metrics for grid-cells in the Eastern and Western U.S. respectively, that enter the concentration response functions for health benefits endpoints. In addition to the standard frequency statistics (e.g., minimum, maximum, average, median), we provide the population-weighted average which better reflects the baseline levels and predicted changes for more populated areas of the nation. This measure, therefore, will better reflect the potential benefits of these predicted changes through exposure changes to these populations.

As shown in Table 9A-8, for the 2020 ozone season, the proposed rule results in average reductions of roughly 2 percent, or between 0.57 to 0.85 ppb, in the daily average ozone concentration metrics across the Eastern U.S. population grid-cells. For the 2030 ozone season, the average reductions in the daily average ozone concentration are between 3 and 3.5 percent, or between 0.91 to 1.35 ppb. A slightly lower relative decline is predicted for the population-weighted average, which reflects the observed increases in ozone concentrations for certain hours during the year in highly populated urban areas associated with NOx emissions reductions (see more detailed discussion in Chapter 2). Additionally, the daily 1-hour maximum ozone concentrations are predicted to decline between 2.3 and 3.6 percent in 2020 and 2030 respectively, i.e., between 1.05 and 1.66 ppb.

As shown in Table 9A-9, for the 2020 ozone season, the proposed rule results in average reductions of roughly 1.5 percent, or between 0.57 to 0.52 ppb, in the daily average ozone concentration metrics across the Western U.S. population grid-cells. For the 2030 ozone season, the average reductions in the daily average ozone concentration are roughly 2 percent, or between 0.61 to 0.82 ppb. Additionally, the daily 1-hour maximum ozone concentrations are predicted to decline between 1.3 and 2.1 percent in 2020 and 2030 respectively, i.e., between 0.62 and 0.97 ppb.

[F] The 8 km grid squares contain the population data used in the health benefits analysis model, CAPMS. See Section C of this appendix for a discussion of this model.

[G] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation (See Abt Associates (2003) for a more detailed description).

As discussed in more detail in Chapter 2, our ozone air quality modeling showed that the NOx emissions reductions from the preliminary modeled standards are projected to result in increases in ozone concentrations for certain hours during the year, especially in urban, NOx limited areas. These increases are often observed within the highly populated urban areas in California. As a result, the population-weighted metrics for ozone shown in Table 9A-9 indicate increases in concentrations. Most of these increases are expected to occur during hours where ozone levels are low (and often below the one-hour ozone standard). These increase are accounted for in the benefits analysis because it relies on the changes in ozone concentrations across the entire distribution of baseline levels. However, as detailed in Chapter 2 and illustrated by the results from Tables 9A-8 and 9A-9, most of the country experiences decreases in ozone concentrations for most hours in the year.

In Table 9A-10, we provide the seasonal SUM06 ozone metric for counties in the Eastern and Western U.S. that enters the concentration response function for agriculture benefit end-points. This metric is a cumulative threshold measure so that the increase in baseline NOx emissions from Tier 2 post-control to this rulemaking have resulted in a larger number of rural counties exceeding the hourly 0.06 ppm threshold. As a result, changes in ozone concentrations for these counties are contributing to greater impacts of the Nonroad Diesel Engine rule on the seasonal SUM06 ozone metric. As shown, the average across all Eastern U.S. counties declined by 78 percent, or almost 17 ppb. Similarly high percentage reductions are observed across the other points on the distribution with the maximum declining by almost 30 ppb, or 55 percent, and the median declining by almost 20 ppb, or 83 percent.

Table 9A-9.
Summary of CAMx Derived Ozone Air Quality Metrics Due to Nonroad Engine/Diesel Fuel Standards for Health Benefits EndPoints: Eastern U.S.

	2020			*2030*		
Statistic [a]	*Base Case*	*Change* [b]	*Percent Change* [b]	*Base Case*	*Change* [b]	*Percent Change* [b]
Daily 1-Hour Maximum Concentration (ppb)						
Minimum [c]	28.85	-0.81	-2.80%	28.81	-1.24	-4.31%
Maximum [c]	93.94	-0.85	-0.90%	94.70	-1.61	-1.70%
Average	45.54	-1.05	-2.30%	45.65	-1.66	-3.64%
Median	45.45	-1.23	-2.71%	45.52	-1.73	-3.80%
Population-Weighted Average [d]	51.34	-0.67	-1.31%	51.47	-1.16	-2.25%
Daily 5-Hour Average Concentration (ppb)						
Minimum [c]	24.90	-0.67	-2.68%	24.87	-1.03	-4.13%
Maximum [c]	68.69	-0.20	-0.29%	69.11	-0.44	-0.64%
Average	38.99	-0.85	-2.17%	39.08	-1.35	-3.45%
Median	38.94	-0.92	-2.39%	39.00	-1.40	-3.58%
Population-Weighted Average [d]	42.77	-0.47	-1.10%	42.90	-0.84	-1.96%
Daily 8-Hour Average Concentration (ppb)						
Minimum [c]	24.15	-0.64	-2.64%	24.12	-0.98	-4.07%
Maximum [c]	68.30	-0.21	-0.31%	68.72	-0.46	-0.67%
Average	38.46	-0.83	-2.16%	38.55	-1.33	-3.44%
Median	38.44	-0.89	-2.33%	38.50	-1.45	-3.76%
Population-Weighted Average [d]	42.07	-0.46	-1.08%	42.19	-0.82	-1.93%
Daily 12-Hour Average Concentration (ppb)						
Minimum [c]	22.42	-0.58	-2.57%	22.40	-0.89	-3.96%
Maximum [c]	66.06	-0.17	-0.25%	66.46	-0.38	-0.58%
Average	36.59	-0.78	-2.13%	36.66	-1.25	-3.40%
Median	36.61	-0.84	-2.30%	36.66	-1.43	-3.89%
Population-Weighted Average [d]	39.65	-0.40	-1.00	39.75	-0.72	-1.80%
Daily 24-Hour Average Concentration (ppb)						
Minimum [c]	15.20	-0.35	-2.28%	15.19	-0.54	-3.52%
Maximum [c]	55.95	0.10	0.18%	56.23	0.04	0.07%
Average	28.93	-0.57	-1.96%	28.98	-0.91	-3.14%
Median	28.92	-0.63	-2.15%	28.98	-1.01	-3.48%
Population-Weighted Average [d]	30.24	-0.18	-0.60%	30.29	-0.37	-1.23%

[a] These ozone metrics are calculated at the CAMX grid-cell level for use in health effects estimates based on the results of spatial and temporal Voronoi Neighbor Averaging. Except for the daily 24-hour average, these ozone metrics are calculated over relevant time periods during the daylight hours of the “ozone season,” i.e., May through September. For the 5-hour average, the relevant time period is 10 am to 3 pm; for the 8-hr average, it is 9 am to 5 pm; and, for the 12-hr average it is 8 am to 8 pm.

[b] The change is defined as the control case value minus the base case value. The percent change is the “Change” divided by the “Base Case,” and then multiplied by 100 to convert the value to a percentage.

[c] The base case minimum (maximum) is the value for the CAMX grid cell with the lowest (highest) value.

[d] Calculated by summing the product of the projected CAMX grid-cell population and the estimated CAMX grid-cell seasonal ozone concentration, and then dividing by the total population.

Table 9A-10.
Summary of CAMx Derived Ozone Air Quality Metrics Due to Nonroad Engine/Diesel Fuel Standards for Health Benefits EndPoints: Western U.S.

	2020			*2030*		
Statistic [a]	*Base Case*	*Change* [b]	*Percent Change* [b]	*Base Case*	*Change* [b]	*Percent Change* [b]
Daily 1-Hour Maximum Concentration (ppb)						
Minimum [c]	27.48	-0.01	-0.03%	27.48	-0.01	-0.05%
Maximum [c]	201.28	4.87	2.42%	208.02	6.26	3.01%
Average	47.02	-0.62	-1.31%	47.04	-0.97	-2.07%
Median	46.10	-0.56	-1.19%	46.06	-0.66	-1.43%
Population-Weighted Average [d]	63.80	0.34	0.54%	64.23	0.38	0.58%
Daily 5-Hour Average Concentration (ppb)						
Minimum [c]	24.20	-0.01	-0.04%	24.21	-0.01	-0.05%
Maximum [c]	163.41	2.55	1.56%	168.89	6.04	3.57%
Average	41.11	-0.52	-1.26%	41.13	-0.82	-2.00%
Median	40.48	-0.40	-1.04%	40.46	-0.69	-1.70%
Population-Weighted Average [d]	53.56	0.45	0.84%	53.89	0.55	1.03%
Daily 8-Hour Average Concentration (ppb)						
Minimum [c]	23.77	-0.01	-0.04%	23.77	-0.01	-0.05%
Maximum [c]	157.49	1.33	0.84%	161.92	5.94	3.67%
Average	40.68	-0.51	-1.25%	40.69	-0.81	-1.99%
Median	40.11	-0.36	-1.03%	40.09	-0.72	-1.79%
Population-Weighted Average [d]	51.96	0.46	0.88%	52.29	0.57	1.10%
Daily 12-Hour Average Concentration (ppb)						
Minimum [c]	22.13	0.31	1.39%	22.09	0.44	2.01%
Maximum [c]	140.48	1.65	1.18%	143.59	1.78	1.24%
Average	39.30	-0.48	-1.23%	39.31	-0.77	-1.95%
Median	38.85	-0.38	-0.97%	38.82	-0.58	-1.50%
Population-Weighted Average [d]	47.68	0.49	1.02%	47.99	0.63	1.32%
Daily 24-Hour Average Concentration (ppb)						
Minimum [c]	14.08	0.22	1.60%	14.03	0.32	2.30%
Maximum [c]	95.27	0.41	0.43%	96.59	0.29	0.30%
Average	33.42	-0.38	-1.14%	33.42	-0.61	-1.82%
Median	32.97	-0.30	-0.89%	32.95	-0.61	-1.85%
Population-Weighted Average [d]	35.53	0.47	1.31%	35.74	0.63	1.77%

[a] These ozone metrics are calculated at the CAMX grid-cell level for use in health effects estimates based on the results of spatial and temporal Voronoi Neighbor Averaging. Except for the daily 24-hour average, these ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season," i.e., May through September. For the 5-hour average, the relevant time period is 10 am to 3 pm; for the 8-hr average, it is 9 am to 5 pm; and, for the 12-hr average it is 8 am to 8 pm.

[b] The change is defined as the control case value minus the base case value. The percent change is the "Change" divided by the "Base Case," and then multiplied by 100 to convert the value to a percentage.

[c] The base case minimum (maximum) is the value for the CAMX grid cell with the lowest (highest) value.

[d] Calculated by summing the product of the projected CAMX grid-cell population and the estimated CAMX grid-cell seasonal ozone concentration, and then dividing by the total population.

Table 9A-11.
Summary of CAMx Derived Ozone Air Quality Metrics Due to Nonroad Engine/Diesel Fuel Standards for Welfare Benefits Endpoints: 2020 and 2030

	2020			*2030*		
Statistic [a]	*Base Case*	*Change* [b]	*Percent Change* [b]	*Base Case*	*Change* [b]	*Percent Change* [b]
Eastern U.S.						
Sum06 (ppm)						
Minimum [c]	0.00	0.00	-	0.00	0.00	-
Maximum [c]	67.24	-3.30	-4.91	68.63	-5.54	-8.07%
Average	4.74	-0.72	-15.10	4.88	-1.09	-22.43%
Median	2.18	-0.76	-35.02	2.21	-0.77	-34.84%
Western U.S.						
Sum06 (ppm)						
Minimum [c]	0.00	0.00	-	0.00	0.00	-
Maximum [c]	132.73	6.09	4.59	137.71	8.45	6.14%
Average	2.78	-0.22	-7.85	2.83	-0.33	-11.72%
Median	0.00	0.00	-	0.00	0.00	-

[a] SUM06 is defined as the cumulative sum of hourly ozone concentrations over 0.06 ppm (or 60 ppb) that occur during daylight hours (from 8am to 8pm) in the months of May through September. It is calculated at the county level for use in agricultural benefits based on the results of temporal and spatial Voronoi Neighbor Averaging.

[b] The change is defined as the control case value minus the base case value. The percent change is the "Change" divided by the "Base Case," which is then multiplied by 100 to convert the value to a percentage.

[c] The base case minimum (maximum) is the value for the county level observation with the lowest (highest) concentration.

9A.2.3 Visibility Degradation Estimates

Visibility degradation is often directly proportional to decreases in light transmittal in the atmosphere. Scattering and absorption by both gases and particles decrease light transmittance. To quantify changes in visibility, our analysis computes a light-extinction coefficient, based on the work of Sisler (1996), which shows the total fraction of light that is decreased per unit distance. This coefficient accounts for the scattering and absorption of light by both particles and gases, and accounts for the higher extinction efficiency of fine particles compared to coarse particles. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon (soot), and soil (Sisler, 1996).

Based upon the light-extinction coefficient, we also calculated a unitless visibility index, called a "deciview," which is used in the valuation of visibility. The deciview metric provides a linear scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

Table 9A-11 provides the distribution of visibility improvements across 2020 and 2030 populations resulting from the Nonroad Engine/Diesel Fuel rule. The majority of the 2030 U.S. population live in areas with predicted improvement in annual average visibility of between 0.4 to 0.6 deciviews resulting from the proposed rule. As shown, almost 20 percent of the 2030 U.S. population are predicted to experience improved annual average visibility of greater than 0.6 deciviews. Furthermore, roughly 70 percent of the 2030 U.S. population will benefit from reductions in annual average visibility of greater than 0.4 deciviews. The information provided in Table 9A-11 indicates how widespread the improvements in visibility are expected to be and the share of populations that will benefit from these improvements.

Because the visibility benefits analysis distinguishes between general regional visibility degradation and that particular to Federally-designated Class I areas (i.e., national parks, forests, recreation areas, wilderness areas, etc.), we separated estimates of visibility degradation into “residential” and “recreational” categories. The estimates of visibility degradation for the “recreational” category apply to Federally-designated Class I areas, while estimates for the “residential” category apply to non-Class I areas. Deciview estimates are estimated using outputs from REMSAD for the 2020 and 2030 base cases and control scenarios.

Table 9A-12.
Distribution of Populations Experiencing Visibility Improvements Due to Nonroad Diesel Engine Standards: 2020 and 2030

Improvements in Visibility [a] (annual average deciviews)	*2020 Population*		*2030 Population*	
	Number (millions)	*Percent (%)*	*Number (millions)*	*Percent (%)*
0 > Δ Deciview ≤ 0.2	52.0	15.8%	11.6	3.3%
0.2 > Δ Deciview ≤ 0.4	115.5	35.0%	179.7	50.5%
0.4 > Δ Deciview ≤ 0.6	81.3	24.7%	90.5	25.4%
0.6 > Δ Deciview ≤ 0.8	62.0	18.8%	49.1	13.8%
0.8 > Δ Deciview ≤ 1.0	13.2	4.0%	16.4	4.6%
Δ Deciview > 1.0	5.6	1.7%	8.5	2.4%

[a] The change is defined as the control case deciview level minus the base case deciview level.

9A.2.3.1 Residential Visibility Improvements

Air quality modeling results predict that the Nonroad Engine/Diesel Fuel rule will create improvements in visibility through the country. In Table 9A-12, we summarize residential visibility improvements across the Eastern and Western U.S. in 2020 and 2030. The baseline annual average visibility for all U.S. counties is 14.8 deciviews. The mean improvement across all U.S. counties is 0.28 deciviews, or almost 2 percent. In urban areas with a population of 250,000 or more (i.e., 1,209 out of 5,147 counties), the mean improvement in annual visibility was 0.39 deciviews and ranged from 0.05 to 1.08 deciviews. In rural areas (i.e., 3,938 counties), the mean improvement in visibility was 0.25 deciviews in 2030 and ranged from 0.02 to 0.94 deciviews.

On average, the Eastern U.S. experienced slightly larger absolute but smaller relative improvements in visibility than the Western U.S. from the Nonroad Engine/Diesel Fuel reductions. In Eastern U.S., the mean improvement was 0.34 deciviews from an average baseline of 19.32 deciviews. Western counties experienced a mean improvement of 0.21 deciviews from an average baseline of 9.75 deciviews projected in 2030. Overall, the data suggest that the Nonroad Engine/Diesel Fuel rule has the potential to provide widespread improvements in visibility for 2030.

Table 9A-13.
Summary of Baseline Residential Visibility and Changes by Region: 2020 and 2030
(Annual Average Deciviews)

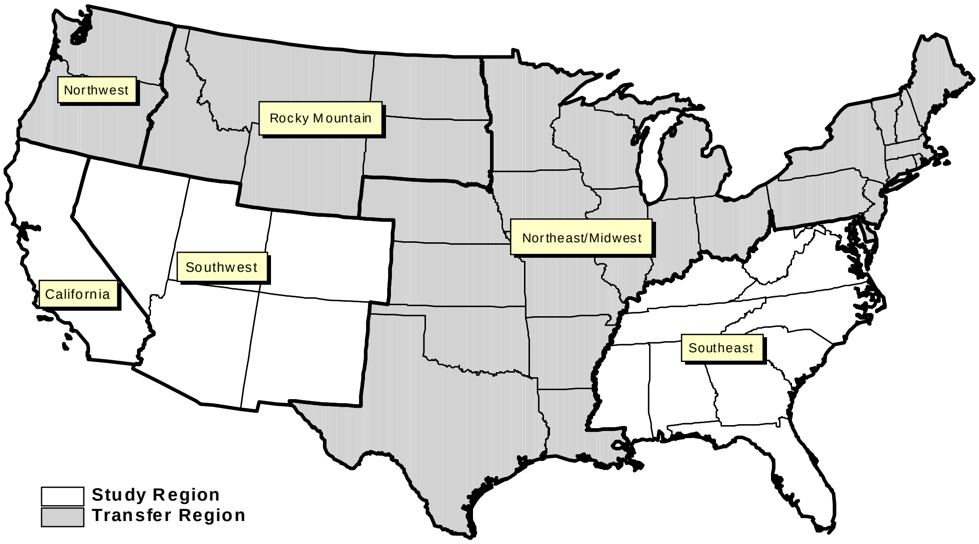
	2020			*2030*		
Regions[a]	*Base Case*	*Change*[b]	*Percent Change*	*Base Case*	*Change*[b]	*Percent Change*
Eastern U.S.	20.27	0.24	1.3%	20.54	0.33	1.7%
Urban	21.61	0.24	1.2%	21.94	0.33	1.6%
Rural	19.73	0.24	1.3%	19.98	0.33	1.8%
Western U.S.	8.69	0.18	2.1%	8.83	0.25	2.8%
Urban	9.55	0.25	2.7%	9.78	0.35	3.6%
Rural	8.50	0.17	2.0%	8.61	0.23	2.7%
National, all counties	14.77	0.21	1.7%	14.98	0.29	2.3%
Urban	17.21	0.24	1.7%	17.51	0.34	2.3%
Rural	14.02	0.20	1.6%	14.20	0.28	2.2%

[a] Eastern and Western regions are separated by 100 degrees north longitude. Background visibility conditions differ by region.
[b] An improvement in visibility is a decrease in deciview value. The change is defined as the Nonroad Engine/Diesel Fuel control case deciview level minus the basecase deciview level.

9A.2.3.2 Recreational Visibility Improvements

In Table 9A-13, we summarize recreational visibility improvements by region in 2020 and 2030 in Federal Class I areas. These recreational visibility regions are shown in Figure 9A-6. As shown, the national improvement in visibility for these areas increases from 1.5 percent, or 0.18 deciviews, in 2020 to 2.1 percent, or 0.24 deciviews, in 2030. Predicted relative visibility improvements are the largest in the Western U.S. as shown for California (3.2% in 2030), and the Southwest (2.9%) and the Rocky Mountain (2.5%). Federal Class I areas in the Eastern U.S. are predicted to have an absolute improvement of 0.24 deciviews in 2030, which reflects a 1.1 to 1.3 percent change from 2030 baseline visibility of 20.01 deciviews.

Figure 9A-6. Recreational Visibility Regions for Continental U.S.



Note: Study regions were represented in the Chestnut and Rowe (1990a, 1990b) studies used in evaluating the benefits of visibility improvements, while transfer regions used extrapolated study results.

Table 9A-14.
Summary of Baseline Recreational Visibility and Changes by Region: 2020 and 2030
(Annual Average Deciviews)

Class I Visibility Regions[a]	*2020*			*2030*		
	Base Case	*Change*[b]	*Percent Change*	*Base Case*	*Change*[b]	*Percent Change*
Eastern U.S.	19.72	0.18	0.9%	20.01	0.24	1.2%
Southeast	21.31	0.18	0.9%	21.62	0.24	1.1%
Northeast/Midwest	18.30	0.18	1.0%	18.56	0.24	1.3%
Western U.S.	8.80	0.17	2.0%	8.96	0.24	2.7%
California	9.33	0.21	2.3%	9.56	0.30	3.2%
Southwest	6.87	0.16	2.3%	7.03	0.21	2.9%
Rocky Mountain	8.46	0.15	1.8%	8.55	0.21	2.5%
Northwest	12.05	0.18	1.5%	12.18	0.24	2.0%
National Average (unweighted)	11.61	0.18	1.5%	11.80	0.24	2.1%

[a] Regions are pictured in Figure VI-5 and are defined in the technical support document (see Abt Associates, 2003).
[b] An improvement in visibility is a decrease in deciview value. The change is defined as the Nonroad Engine/Diesel Fuel control case deciview level minus the basecase deciview level.

9A.3 Benefit Analysis- Data and Methods

Environmental and health economists have a number of methods for estimating the economic value of improvements in (or deterioration of) environmental quality. The method used in any given situation depends on the nature of the effect and the kinds of data, time, and resources that are available for investigation and analysis. This section provides an overview of the methods we selected to quantify and monetize the benefits included in this RIA.

Given changes in environmental quality (ambient air quality, visibility, nitrogen and sulfate deposition), the next step is to determine the economic value of those changes. We follow a "damage-function" approach in calculating total benefits of the modeled changes in environmental quality. This approach estimates changes in individual health and welfare endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the individual values. Total benefits are calculated simply as the sum of the values for all non-overlapping health and welfare endpoints. This imposes no overall preference structure, and does not account for potential income or substitution effects, i.e. adding a new endpoint will not reduce the value of changes in other endpoints. The "damage-function" approach is the standard approach for most cost-benefit analyses of environmental quality programs, and has been used in several recent published analyses (Banzhaf et al., 2002; Levy et al, 2001; Levy et al, 1999; Ostro and Chestnut, 1998).

In order to assess economic value in a damage-function framework, the changes in environmental quality must be translated into effects on people or on the things that people value. In some cases, the changes in environmental quality can be directly valued, as is the case for changes in visibility. In other cases, such as for changes in ozone and PM, a health and welfare impact analysis must first be conducted to convert air quality changes into effects that can be assigned dollar values.

For the purposes of this RIA, the health impacts analysis is limited to those health effects that are directly linked to ambient levels of air pollution, and specifically to those linked to ozone and particulate matter. There are known health effects associated with other emissions expected to be reduced by these standards, however, due to limitations in air quality models, we are unable to quantify the changes in the ambient levels of CO, SO_2, and air toxics such as benzene. There may be other, indirect health impacts associated with implementation of controls to meet the preliminary control options, such as occupational health impacts for equipment operators. These impacts may be positive or negative, but in general, for this set of preliminary control options, are expected to be small relative to the direct air pollution related impacts.

The welfare impacts analysis is limited to changes in the environment that have a direct impact on human welfare. For this analysis, we are limited by the available data to examining impacts of changes in visibility and agricultural yields. We also provide qualitative discussions of the impact of changes in other environmental and ecological effects, for example, changes in deposition of nitrogen and sulfur to terrestrial and aquatic ecosystems, but we are unable to place an economic value on these changes.

We note at the outset that EPA rarely has the time or resources to perform extensive new research to measure either the health outcomes or their values for this analysis. Thus, similar to Kunzli et al (2000) and other recent health impact analyses, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Where appropriate, adjustments are made for the level of environmental quality change, the sociodemographic and economic characteristics of the affected population, and other factors in order to improve the accuracy and robustness of benefits estimates.

9A.3.1 Valuation Concepts

In valuing health impacts, we note that reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore willingness-to-pay for changes in risk prior to the regulation (Freeman, 1993). In general, economists tend to view an individual’s willingness-to-pay (WTP) for a improvement in environmental quality as the appropriate measure of the value of a risk reduction. An individual’s willingness-to-accept (WTA) compensation for not receiving the improvement is also a valid measure. However, WTP is generally considered to be a more readily available and conservative measure of benefits. Adoption of WTP as the measure of value implies that the value of environmental quality improvements is dependent on the individual preferences of the affected population and that the existing distribution of income (ability to pay) is appropriate. For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as a primary estimate. These costs of illness (COI) estimates generally understate the true value of reductions in risk of a health effect, reflecting the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect (Harrrington and Portnoy, 1987; Berger, 1987).

For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for one dollar, it can be observed that at least some persons are willing to pay one dollar for such water. For goods not exchanged in the market, such as most environmental "goods," valuation is not as straightforward. Nevertheless, a value may be inferred from observed behavior, such as sales and prices of products that result in similar effects or risk reductions, (e.g., non-toxic cleaners or bike helmets). Alternatively, surveys may be used in an attempt to directly elicit WTP for an environmental improvement.

One distinction in environmental benefits estimation is between use values and non-use values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman, 1993), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare more or less directly. These effects include changes in product prices, quality, and availability, changes in the quality of outdoor recreation and outdoor aesthetics, changes in health or life expectancy, and the costs of actions taken to avoid negative effects of environmental quality changes.

Non-use values are those for which an individual is willing to pay for reasons that do not relate to the direct use or enjoyment of any environmental benefit, but might relate to existence values and bequest values. Non-use values are not traded, directly or indirectly, in markets. For this reason, the measurement of non-use values has proved to be significantly more difficult than the measurement of use values. The air quality changes produced by the Nonroad Diesel Engine rule cause changes in both use and non-use values, but the monetary benefit estimates are almost exclusively for use values.

More frequently than not, the economic benefits from environmental quality changes are not traded in markets, so direct measurement techniques can not be used. There are three main non-market valuation methods used to develop values for endpoints considered in this analysis. These include stated preference (or contingent valuation), indirect market (e.g. hedonic wage), and avoided cost methods.

The stated preference or CV method values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to a given change in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of stated preference based valuation. EPA believes that well-designed and well-executed stated preference studies are valid for estimating the benefits of air quality regulation.[h] Stated preference valuation studies form the basis for valuing a number of health

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[H] Concerns about the reliability of value estimates from CV studies arose because research has shown that bias can be introduced easily into these studies if they are not carefully conducted. Accurately measuring WTP for avoided health and welfare losses depends on the reliability and validity of the data collected. There are several and welfare endpoints, including the value of mortality risk reductions, chronic bronchitis risk reductions, minor illness risk reductions, and visibility improvements.

Indirect market methods can also be used to infer the benefits of pollution reduction. The most important application of this technique for our analysis is the calculation of the value of a statistical life for use in the estimate of benefits from mortality risk reductions. There exists no market where changes in the probability of death are directly exchanged. However, people make decisions about occupation, precautionary behavior, and other activities associated with changes in the risk of death. By examining these risk changes and the other characteristics of people's choices, it is possible to infer information about the monetary values associated with changes in mortality risk (see Section 9A.3.5.5.1).

Avoided cost methods are ways to estimate the costs of pollution by using the expenditures made necessary by pollution damage. For example, if buildings must be cleaned or painted more frequently as levels of PM increase, then the appropriately calculated increment of these costs is a reasonable lower bound estimate (under most conditions) of true economic benefits when PM levels are reduced. Avoided costs methods are also used to estimate some of the health-related benefits related to morbidity, such as hospital admissions (see section 9A.3.5).

The most direct way to measure the economic value of air quality changes is in cases where the endpoints have market prices. For the final rule, this can only be done for effects on commercial agriculture. Well-established economic modeling approaches are used to predict price changes that result from predicted changes in agricultural outputs. Consumer and producer surplus measures can then be developed to give reliable indications of the benefits of changes in ambient air quality for this category (see Section 9A.3.6.2).

9A.3.2 Growth in WTP Reflecting National Income Growth Over Time

Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. There is substantial empirical evidence that the income elasticity[i] of WTP for health risk reductions is positive, although there is uncertainty about its exact value. Thus, as real income increases the WTP for environmental improvements also increases. While many analyses assume that the income elasticity of WTP is unit elastic (i.e., ten percent higher real income level implies a ten percent higher WTP to reduce risk changes), empirical evidence

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issues to consider when evaluating study quality, including but not limited to 1) whether the sample estimates of WTP are representative of the population WTP; 2) whether the good to be valued is comprehended and accepted by the respondent; 3) whether the WTP elicitation format is designed to minimize strategic responses; 4) whether WTP is sensitive to respondent familiarity with the good, to the size of the change in the good, and to income; 5) whether the estimates of WTP are broadly consistent with other estimates of WTP for similar goods; and 6) the extent to which WTP responses are consistent with established economic principles.

[i] Income elasticity is a common economic measure equal to the percentage change in WTP for a one percent change in income.

suggests that income elasticity is substantially less than one and thus relatively inelastic. As real income rises, the WTP value also rises but at a slower rate than real income.

The effects of real income changes on WTP estimates can influence benefit estimates in two different ways: (1) through real income growth between the year a WTP study was conducted and the year for which benefits are estimated, and (2) through differences in income between study populations and the affected populations at a particular time. Empirical evidence of the effect of real income on WTP gathered to date is based on studies examining the former. The Environmental Economics Advisory Committee (EEAC) of the SAB advised EPA to adjust WTP for increases in real income over time, but not to adjust WTP to account for cross-sectional income differences “because of the sensitivity of making such distinctions, and because of insufficient evidence available at present” (EPA-SAB-EEAC-00-013).

Based on a review of the available income elasticity literature, we adjust the valuation of human health benefits upward to account for projected growth in real U.S. income. Faced with a dearth of estimates of income elasticities derived from time-series studies, we applied estimates derived from cross-sectional studies in our analysis. Details of the procedure can be found in Kleckner and Neumann (1999). An abbreviated description of the procedure we used to account for WTP for real income growth between 1990 and 2030 is presented below.

Reported income elasticities suggest that the severity of a health effect is a primary determinant of the strength of the relationship between changes in real income and WTP. As such, we use different elasticity estimates to adjust the WTP for minor health effects, severe and chronic health effects, and premature mortality. We also expect that the WTP for improved visibility in Class I areas would increase with growth in real income. The elasticity values used to adjust estimates of benefits in 2020 and 2030 are presented in Table 9A-11.

Table 9A-15. Elasticity Values Used to Account for Projected Real Income Growth[A]

Benefit Category	Central Elasticity Estimate
Minor Health Effect	0.14
Severe and Chronic Health Effects	0.45
Premature Mortality	0.40
Visibility[B]	0.90

[A] Derivation of estimates can be found in Kleckner and Neumann (1999) and Chestnut (1997). Cost of Illness (COI) estimates are assigned an adjustment factor of 1.0.

[B] No range was applied for visibility because no ranges were available in the current published literature.

In addition to elasticity estimates, projections of real GDP and populations from 1990 to 2020 and 2030 are needed to adjust benefits to reflect real per capita income growth. For consistency with the emissions and benefits modeling, we use national population estimates for the years 1990 to 1999 based on U.S. Census Bureau estimates (Hollman, Mulder and Kallan, 2000). These population estimates are based on application of a cohort-component model applied to 1990 U.S. Census data projections[j]. For the years between 2000 and 2030, we applied growth rates based on the U.S. Census Bureau projections to the U.S. Census estimate of national population in 2000. We use projections of real GDP provided in Kleckner and Neumann (1999) for the years 1990 to 2010[k]. We use projections of real GDP (in chained 1996 dollars) provided by Standard and Poor's[l] for the years 2010 to 2024. The Standard and Poor's database only provides estimates of real GDP between 1990 and 2024. We were unable to find reliable projections of GDP past 2024. As such, we assume that per capita GDP remains constant between 2024 and 2030.

Using the method outlined in Kleckner and Neumann (1999), and the population and income data described above, we calculate WTP adjustment factors for each of the elasticity estimates listed in Table 1. Benefits for each of the categories (minor health effects, severe and chronic health effects, premature mortality, and visibility) will be adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor. Table 2 lists the estimated adjustment factors. Note that for premature mortality, we apply the income adjustment factor ex post to the present discounted value of the stream of avoided mortalities occurring over the lag period. Also note that no adjustments will be made to benefits based on the cost-of-illness approach or to work loss days and worker productivity. This assumption will also lead us to under predict benefits in future years since it is likely that increases in real U.S. income would also result in increased cost-of-illness (due, for example, to increases in wages paid to medical workers) and increased cost of work loss days and lost worker productivity (reflecting that if worker incomes are higher, the losses resulting from reduced worker production would also be higher). No adjustments are needed for agricultural benefits, as the model is based on projections of supply and demand in future years and should already incorporate future changes in real income.

[J] U.S. Bureau of Census. Annual Projections of the Total Resident Population, Middle Series, 1999-2100. (Available on the internet at http://www.census.gov/population/www/projections/natsum-T1.html)

[K] U.S. Bureau of Economic Analysis, Table 2A (1992$). (Available on the internet at http://www.bea.doc.gov/bea/dn/0897nip2/tab2a.htm) and U.S. Bureau of Economic Analysis, Economics and Budget Outlook. Note that projections for 2007 to 2010 are based on average GDP growth rates between 1999 and 2007.

[L] Standard and Poor's. 2000. "The U.S. Economy: The 25 Year Focus." Winter.

Table 9A-16. Adjustment Factors Used to Account for Projected Real Income Growth[A]

Benefit Category	2020	2030[B]
Minor Health Effect	1.084	1.092
Severe and Chronic Health Effects	1.299	1.329
Premature Mortality	1.262	1.287
Visibility	1.704	1.787

[A] Based on elasticity values reported in Table 9A-11, US Census population projections, and projections of real gross domestic product per capita.
B Income growth adjustment factor for 2030 is based on an assumption that there is no growth in per capita income between 2024 and 2030, based on a lack of available GDP projections beyond 2024.

9A.3.3 Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty.[m] This analysis is no exception. As outlined both in this and preceding chapters, there are many inputs used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological estimates of concentration-response (C-R) functions, estimates of values (both from WTP and cost-of-illness studies), population estimates, income estimates, and estimates of the future state of the world (i.e., regulations, technology, and human behavior). Each of these inputs may be uncertain, and depending on their location in the benefits analysis, may have a disproportionately large impact on final estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to much larger impacts on total benefits. A more thorough discussion of uncertainty can be found in the benefits technical support document (TSD) (Abt Associates, 2003).

Some key sources of uncertainty in each stage of the benefits analysis are:

- Gaps in scientific data and inquiry;
- Variability in estimated relationships, such as C-R functions, introduced through differences in study design and statistical modeling;
- Errors in measurement and projection for variables such as population growth rates;

[M] It should be recognized that in addition to uncertainty, the annual benefit estimates for the Nonroad Diesel Engines rulemaking presented in this analysis are also inherently variable, due to the truly random processes that govern pollutant emissions and ambient air quality in a given year. Factors such as engine hours and weather display constant variability regardless of our ability to accurately measure them. As such, the estimates of annual benefits should be viewed as representative of the types of benefits that will be realized, rather than the actual benefits that would occur every year.

- Errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and
- Biases due to omissions or other research limitations.

Some of the key uncertainties in the benefits analysis are presented in Table 9A-13. Given the wide variety of sources for uncertainty and the potentially large degree of uncertainty about any primary estimate, it is necessary for us to address this issue in several ways, based on the following types of uncertainty:

a. *Quantifiable uncertainty in benefits estimates.* For some parameters or inputs it may be possible to provide a statistical representation of the underlying uncertainty distribution. Quantitative uncertainty may include measurement uncertainty or variation in estimates across or within studies. For example, the variation in VSL results across the 26 studies that underlie the Base Estimate represent a quantifiable uncertainty.

b. *Uncertainty in the basis for quantified estimates*. Often it is possible to identify a source of uncertainty (for example, an ongoing debate over the proper method to estimate premature mortality) that is not readily addressed through traditional uncertainty analysis. In these cases, it is possible to characterize the potential impact of this uncertainty on the overall benefits estimates through sensitivity analyses.

c. *Nonquantifiable uncertainty.* Uncertainties may also result from omissions of known effects from the benefits calculation, perhaps owing to a lack of data or modeling capability. For example, in this analysis we were unable to quantify the benefits of avoided airborne nitrogen deposition on aquatic and terrestrial ecosystems, or avoided health and environmental effects associated with reductions in CO emissions.

It should be noted that even for individual endpoints, there is usually more than one source of uncertainty. This makes it difficult to provide an overall quantified uncertainty estimate for individual endpoints or for total benefits. For example, the C-R function used to estimate avoided premature mortality has an associated standard error which represents the sampling error around the pollution coefficient in the estimated C-R function. It is possible to report a confidence interval around the estimated incidences of avoided premature mortality based on this standard error. However, this would omit the contribution of air quality changes, baseline population incidences, projected populations exposed, and transferability of the C-R function to diverse locations to uncertainty about premature mortality. Thus, a confidence interval based on the standard error gives a misleading picture about the overall uncertainty in the estimates. Information on the uncertainty surrounding particular C-R and valuation functions is provided in the benefits TSD for this RIA (Abt Associates, 2003). But, this information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

Our approach to characterizing model uncertainty is to present a primary estimate of the benefits, based on the best available scientific literature and methods, and to then provide sensitivity analyses to illustrate the effects of uncertainty about key analytical assumptions. Our analysis of the preliminary control options has not included formal integrated uncertainty analyses, although we have conducted several sensitivity tests and have analyzed a full Alternative Estimate based on changes to several key model parameters. The recent NAS report on estimating public health benefits of air pollution regulations recommended that EPA begin to move the assessment of uncertainties from its ancillary analyses into its primary analyses by conducting probabilistic, multiple-source uncertainty analyses. We are working to implement these recommendations. At this time, we simply demonstrate the sensitivity of our benefits results to key parameters which may be uncertain. Sensitivity estimates are presented in Appendix 9B.

Our estimate of total benefits should be viewed as an approximate result because of the sources of uncertainty discussed above (see Table 9A-13). Uncertainty about specific aspects of the health and welfare estimation models are discussed in greater detail in the following sections and in the benefits TSD (Abt Associates, 2003). The total benefits estimate may understate or overstate actual benefits of the rule.

In considering the monetized benefits estimates, the reader should remain aware of the many limitations of conducting these analyses mentioned throughout this RIA. One significant limitation of both the health and welfare benefits analyses is the inability to quantify many of the serious effects listed in Table 9A-1. For many health and welfare effects, such as changes in ecosystem functions and PM-related materials damage, reliable C-R functions and/or valuation functions are not currently available. In general, if it were possible to monetize these benefits categories, the benefits estimates presented in this analysis would increase. Unquantified benefits are qualitatively discussed in the health and welfare effects sections. In addition to unquantified benefits, there may also be environmental costs that we are unable to quantify. Several of these environmental cost categories are related to nitrogen deposition, while one category is related to the issue of ultraviolet light. These endpoints are qualitatively discussed in the health and welfare effects sections as well. The net effect of excluding benefit and disbenefit categories from the estimate of total benefits depends on the relative magnitude of the effects.

Table 9A-17. Primary Sources of Uncertainty in the Benefit Analysis

1. Uncertainties Associated With Concentration-Response Functions
– The value of the ozone- or PM-coefficient in each C-R function. – Application of a single C-R function to pollutant changes and populations in all locations. – Similarity of future year C-R relationships to current C-R relationships. – Correct functional form of each C-R relationship. – Extrapolation of C-R relationships beyond the range of ozone or PM concentrations observed in the study. – Application of C-R relationships only to those subpopulations matching the original study population.
2. Uncertainties Associated With Ozone and PM Concentrations
– Responsiveness of the models to changes in precursor emissions resulting from the control policy. – Projections of future levels of precursor emissions, especially ammonia and crustal materials. – Model chemistry for the formation of ambient nitrate concentrations. – Lack of ozone monitors in rural areas requires extrapolation of observed ozone data from urban to rural areas. – Use of separate air quality models for ozone and PM does not allow for a fully integrated analysis of pollutants and their interactions. – Full ozone season air quality distributions are extrapolated from a limited number of simulation days. – Comparison of model predictions of particulate nitrate with observed rural monitored nitrate levels indicates that REMSAD overpredicts nitrate in some parts of the Eastern US and underpredicts nitrate in parts of the Western US.
3. Uncertainties Associated with PM Mortality Risk
– No scientific literature supporting a direct biological mechanism for observed epidemiological evidence. – Direct causal agents within the complex mixture of PM have not been identified. – The extent to which adverse health effects are associated with low level exposures that occur many times in the year versus peak exposures. – The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. – Reliability of the limited ambient $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated With Possible Lagged Effects
– The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated With Baseline Incidence Rates
– Some baseline incidence rates are not location-specific (e.g., those taken from studies) and may therefore not accurately represent the actual location-specific rates. – Current baseline incidence rates may not approximate well baseline incidence rates in 2030. – Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated With Economic Valuation
– Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. – Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates due to differences in income or other factors. – Future markets for agricultural and forestry products are uncertain.
7. Uncertainties Associated With Aggregation of Monetized Benefits
– Health and welfare benefits estimates are limited to the available C-R functions. Thus, unquantified or unmonetized benefits are not included.

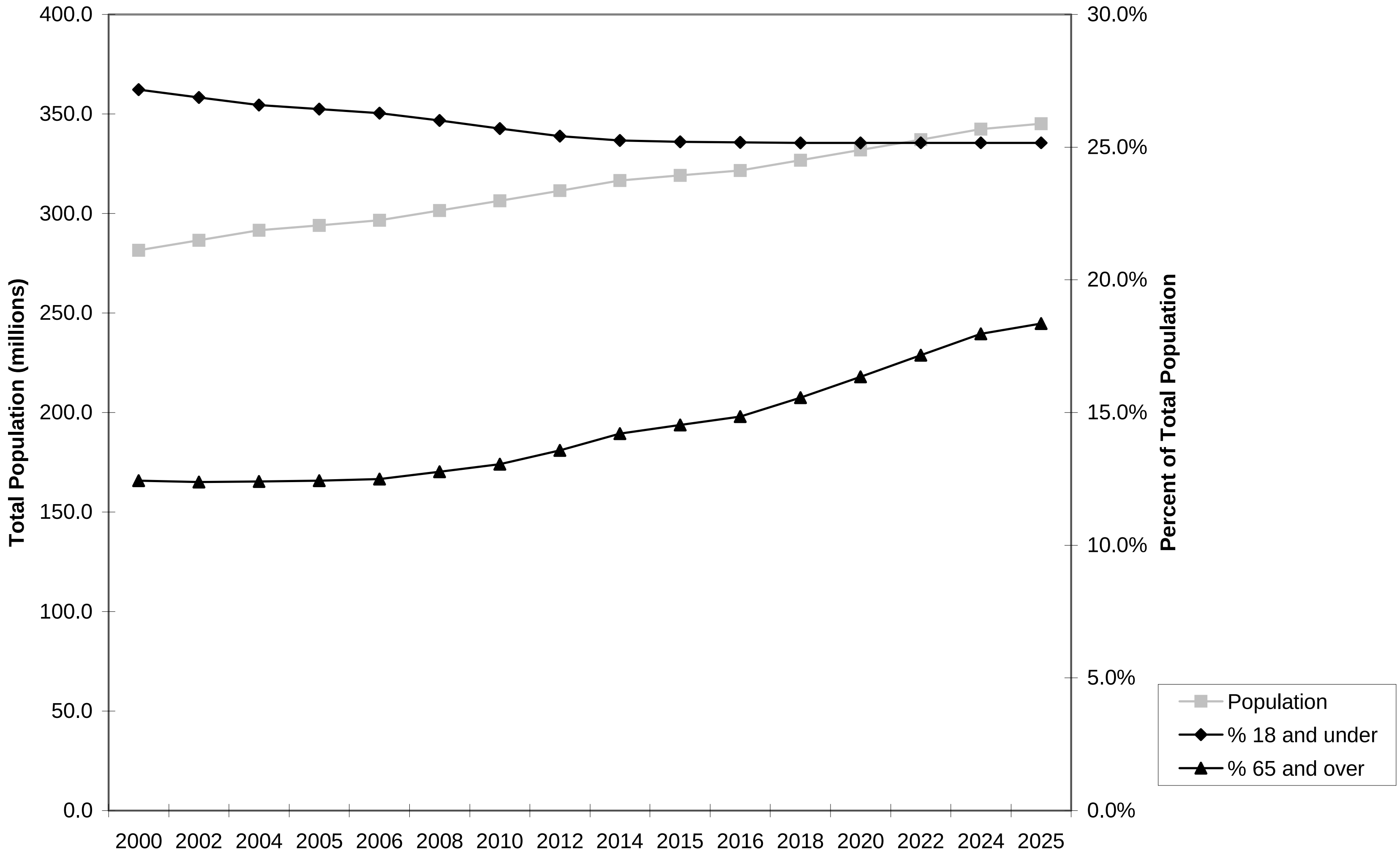
9A.3.4 Demographic Projections

Quantified and monetized human health impacts depend critically on the demographic characteristics of the population, including age, location, and income. In previous analyses, we have used simple projections of total population that did not take into account changes in demographic composition over time. In the current analysis, we use more sophisticated projections based on economic forecasting models developed by Woods and Poole, Inc. The Woods and Poole (WP) database contains county level projections of population by age, sex, and race out to 2025. Projections in each county are determined simultaneously with every other county in the U.S. to take into account patterns of economic growth and migration. The sum of growth in county level populations is constrained to equal a previously determined national population growth, based on Bureau of Census estimates (Hollman, Mulder and Kallan, 2000). According to WP, linking county level growth projections together and constraining to a national level total growth avoids potential errors introduced by forecasting each county independently. County projections are developed in a four stage process. First, national level variables such as income, employment, populations, etc. are forecasted. Second, employment projections are made for 172 economic areas defined by the Bureau of Economic Analysis, using an "export-base" approach, which relies on linking industrial sector production of non-locally consumed production items, such as outputs from mining, agriculture, and manufacturing with the national economy. The export-base approach requires estimation of demand equations or calculation of historical growth rates for output and employment by sector. Third, population is projected for each economic area based on net migration rates derived from employment opportunities, and following a cohort-component method based on fertility and mortality in each area. Fourth, employment and population projections are repeated for counties, using the economic region totals as bounds. The age, sex, and race distributions for each region or county are determined by aging the population by single year of age by sex and race for each year through 2025 based on historical rates of mortality, fertility, and migration.

The WP projections of county level population are based on historical population data from 1969-1999, and do not include the 2000 Census results. Given the availability of detailed 2000 Census data, we constructed adjusted county level population projections for each future year using a two stage process. First, we constructed ratios of the projected WP populations in a future year to the projected WP population in 2000 for each future year by age, sex, and race. Second, we multiplied the block level 2000 Census population data by the appropriate age, sex, and race specific WP ratio for the county containing the census block, for each future year. This results in a set of future population projections that is consistent with the most recent detailed census data. The WP projections extend only through 2025. To calculate populations for 2030, we applied the growth rate from 2024 to 2025 to each year between 2025 and 2030.

Figure 9A-7 shows the projected trends in total U.S. population and the percentage of total population aged zero to eighteen and over 65. This figure illustrates that total populations are projected increase from 281 million in 2000 to 345 million in 2025. The percent of the population 18 and under is expected to decrease slightly, from 27 to 25 percent, and the percent of the population over 65 is expected to increase from 12 percent to 18 percent.

Figure 9A-7.
Projections of U.S. Population, 2000-2025



As noted above, values for environmental quality improvements are expected to increase with growth in real per capita income. Accounting for real income growth over time requires projections of both real gross domestic product (GDP) and total U.S. populations. For consistency with the emissions and benefits modeling, we use national population estimates based on the U.S. Census Bureau projections. We use projections of real GDP provided in Kleckner and Neumann (1999) for the years 1990 to 2010.[n] We use projections of real GDP (in chained 1996 dollars) provided by Standard and Poor's for the years 2010 to 2024.[o] The Standard and Poor's database only provides estimates of real GDP between 1990 and 2024. We were unable to find reliable projections of GDP beyond 2024. As such, we assume that per capita GDP remains constant between 2024 and 2030. This assumption will lead us to under-predict benefits because at least some level of income growth would be projected to occur between the years 2024 and 2030.

9A.3.5 Health Benefits Assessment Methods

The most significant monetized benefits of reducing ambient concentrations of PM and ozone are attributable to reductions in health risks associated with air pollution. EPA's Criteria Documents for ozone and PM list numerous health effects known to be linked to ambient concentrations of these pollutants (US EPA, 1996a and 1996b). As illustrated in Figure 9A.1, quantification of health impacts requires several inputs, including concentration-response functions, baseline incidence and prevalence rates, potentially affected populations, and estimates of changes in ambient concentrations of air pollution. Previous sections have described the population and air quality inputs. This section describes the C-R functions and baseline incidence and prevalence inputs, and the methods used to quantify and monetize changes in the expected number of incidences of various health effects.

9A.3.5.1 Selecting Concentration-Response Functions

Quantifiable health benefits of the modeled preliminary control options may be related to ozone only, PM only, or both pollutants. Decreased worker productivity, respiratory hospital admissions for children under two, and school absences are related to ozone but not PM. PM-only health effects include premature mortality, non-fatal heart attacks, asthma emergency room visits, chronic bronchitis, acute bronchitis, upper and lower respiratory symptoms, and work loss

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[N] US Bureau of Economic Analysis, Table 2A (1992$). (Available on the internet at http://www.bea.doc.gov/bea/dn/0897nip2/tab2a.htm) and US Bureau of Economic Analysis, Economics and Budget Outlook. Note that projections for 2007 to 2010 are based on average GDP growth rates between 1999 and 2007.

[O] Standard and Poor's. 2000. "The U.S. Economy: The 25 Year Focus." Winter 2000.

days.[p] Health effects related to both PM and ozone include hospital admissions and minor restricted activity days.

We relied on the available published scientific literature to ascertain the relationship between particulate matter and ozone exposure and adverse human health effects. We evaluated studies using the selection criteria summarized in Table 9A-18. These criteria include consideration of whether the study was peer-reviewed, the match between the pollutant studied and the pollutant of interest, the study design and location, and characteristics of the study population, among other considerations. The selection of C-R functions for the benefits analysis is guided by the goal of achieving a balance between comprehensiveness and scientific defensibility.

Recently, the Health Effects Institute (HEI) reported findings by health researchers at Johns Hopkins University and others that have raised concerns about aspects of the statistical methods used in a number of recent time-series studies of short-term exposures to air pollution and health effects (Greenbaum, 2002). The estimates derived from the long-term exposure studies, which account for a major share of the economic benefits described in Chapter 9, are not affected. Similarly, the time-series studies employing generalized linear models (GLMs) or other parametric methods, as well as case-crossover studies, are not affected. As discussed in HEI materials provided to EPA and to CASAC (Greenbaum, 2002), researchers working on the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) found problems in the default "convergence criteria" used in Generalized Additive Models (GAM) and a separate issue first identified by Canadian investigators about the potential to underestimate standard errors in the same statistical package. These and other scientists have begun to reanalyze the results of several important time series studies with alternative approaches that address these issues and have found a downward revision of some results. For example, the mortality risk estimates for short-term exposure to PM_{10} from NMMAPS were overestimated (this study was not used in this benefits analysis of fine particle effects). However, both the relative magnitude and the direction of bias introduced by the convergence issue is case-specific. In most cases, the concentration-response relationship may be overestimated; in other cases, it may be underestimated. The preliminary reanalyses of the mortality and morbidity components of NMMAPS suggest that analyses reporting the lowest relative risks appear to be affected more greatly by this error than studies reporting higher relative risks (Domenici et al, 2002).

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[p] Some evidence has been found linking both PM and ozone exposures with premature mortality. The SAB has raised concerns that mortality-related benefits of air pollution reductions may be overstated if separate pollutant-specific estimates, some of which may have been obtained from models excluding the other pollutants, are aggregated. In addition, there may be important interactions between pollutants and their effect on mortality (EPA-SAB-Council-ADV-99-012, 1999).

Because of concern about overstating of benefits and because the evidence associating mortality with exposure to PM is currently stronger than for ozone, only the benefits related to the long-term exposure study (ACS/Krewkski, et al, 2000) of mortality are included in the total primary benefits estimate. The benefits associated with ozone reductions are presented as a sensitivity analysis in Appendix 9-B but are not included in the estimate of total benefits.

During the compilation of the draft Air Quality Criteria Document, examination of the original studies used in our benefits analysis found that the health endpoints that are potentially affected by the GAM issues include: reduced hospital admissions in both the Base and Alternative Estimates, reduced lower respiratory symptoms in both the Base and Alternative Estimates, and reduced premature mortality due to short-term PM exposures in the Alternative Estimate. While resolution of these issues is likely to take some time, the preliminary results from ongoing reanalyses of some of the studies used in our analyses (Dominici et al, 2002; Schwartz and Zanobetti, 2002; Schwartz, personal communication 2002) suggest a more modest effect of the S-plus error than reported for the NMMAPS PM_{10} mortality study. In December 2002, a number of researchers submitted reanalysis reports, and the HEI is currently coordinating review of these reports by a peer review panel. The final report on these reanalyses is expected by the end of April 2003, and the results will be incorporated in the fourth external review draft of the Criteria Document that will be released in summer 2003. While we wait for further clarification from the scientific community, we have chosen not to remove these results from the Nonroad Diesel benefits estimates, nor have we elected to apply any interim adjustment factor based on the preliminary reanalyses EPA will continue to monitor the progress of this concern, and make appropriate adjustments as further information is made available.

While a broad range of serious health effects have been associated with exposure to elevated ozone and PM levels (as noted for example in Table 9A-1 and described more fully in the ozone and PM Criteria Documents (US EPA, 1996a, 1996b), we include only a subset of health effects in this quantified benefit analysis. Health effects are excluded from this analysis for three reasons: (i) the possibility of double counting (such as hospital admissions for specific respiratory diseases); (ii) uncertainties in applying effect relationships based on clinical studies to the affected population; or (iii) a lack of an established C-R relationship.

In general, the use of results from more than a single study can provide a more robust estimate of the relationship between a pollutant and a given health effect. However, there are often differences between studies examining the same endpoint which make it difficult to pool the results in a consistent manner. For example, studies may examine different pollutants, or different age groups. For this reason, we consider very carefully the set of studies available examining each endpoint, and select a consistent subset that provides a good balance of population coverage and match with the pollutant of interest. In many cases, either due to a lack of multiple studies, consistency problems, or clear superiority in the quality or comprehensiveness of one study over others, a single published study is selected as the basis of the C-R relationship.

When several estimated C-R relationships between a pollutant and a given health endpoint have been selected, they are quantitatively combined or pooled to derive a more robust estimate of the relationship. The benefits TSD provides details of the procedures used to combine multiple C-R functions (Abt Associates, 2003). In general, we use fixed or random effects models to pool estimates from different studies of the same endpoint. Fixed effects pooling simply weights each studies estimate by the inverse variance, giving more weight to studies with greater statistical power (lower variance). Random effects pooling accounts for both within-study variance and between-study variability, due for example to differences in population susceptibility. We use the fixed effects model as our null hypothesis, and then determine whether the data suggest that we should reject this null hypothesis, in which case we would use the random effects model.[q] Pooled C-R functions are used to estimate hospital admissions related to PM and asthma-related emergency room visits related to ozone. For more details on methods used to pool incidence estimates, see the benefits TSD (Abt Associates, 2003).

Concentration-response relationships between a pollutant and a given health endpoint are applied consistently across all locations nationwide. This applies to both C-R relationships defined by a single C-R function and those defined by a pooling of multiple C-R functions. Although the C-R relationship may, in fact, vary from one location to another (for example, due to differences in population susceptibilities or differences in the composition of PM), location-specific C-R functions are generally not available.

The specific studies from which C-R functions for calculating the Base and Alternative estimates are drawn are included in Table 9A-14. A complete discussion of the C-R functions used for this analysis and information about each endpoint are contained in the benefits TSD for this RIA (Abt Associates, 2003). Basic information on each endpoint is presented below.

[Q] The fixed effects model assumes that there is only one pollutant coefficient for the entire modeled area. The random effects model assumes that different studies are estimating different parameters, and therefore there may be a number of different underlying pollutant coefficients.

Table 9A-18.
Summary of Considerations Used in Selecting C-R Functions

Consideration	Comments
Peer reviewed research	Peer reviewed research is preferred to research that has not undergone the peer review process.
Study type	Among studies that consider chronic exposure (e.g., over a year or longer) prospective cohort studies are preferred over cross-sectional studies because they control for important individual-level confounding variables that cannot be controlled for in cross-sectional studies.
Study period	Studies examining a relatively longer period of time (and therefore having more data) are preferred, because they have greater statistical power to detect effects. More recent studies are also preferred because of possible changes in pollution mixes, medical care, and life style over time. However, when there are only a few studies available, studies from all years will be included.
Population attributes	The most tecnically appropriate measures of benefits would be based on C-R functions that cover the entire sensitive population, but allow for heterogeneity across age or other relevant demographic factors. In the absence of C-R functions specific to age, sex, preexisting condition status, or other relevant factors, it may be appropriate to select C-R functions that cover the broadest popuation, to match with the desired outcome of the analysis, which is total national-level health impacts.
Study size	Studies examining a relatively large sample are preferred because they generally have more power to detect small magnitude effects. A large sample can be obtained in several ways, either through a large population, or through repeated observations on a smaller population, i.e. through a symptom diary recorded for a panel of asthmatic children.
Study location	U.S. studies are more desirable than non-U.S. studies because of potential differences in pollution characteristics, exposure patterns, medical care system, population behavior and life style.
Pollutants included in model	When modeling the effects of ozone and PM (or other pollutant combinations) jointly, it is important to use properly specified C-R functions that include both pollutants. Use of single pollutant models in cases where both pollutants are expected to affect a health outcome can lead to double-counting when pollutants are correlated.
Measure of PM	For this analysis, C-R functions based on $PM_{2.5}$ are preferred to PM_{10} because reductions in emissions from diesel engines are expected to reduce fine particles and not have much impact on coarse particles. Where $PM_{2.5}$ functions are not available, PM_{10} functions are used as surrogates, recognizing that there will be potential downward (upward) biases if the fine fraction of PM_{10} is more (less) toxic than the coarse fraction.
Economically valuable health effects	Some health effects, such as forced expiratory volume and other technical measurements of lung function, are difficult to value in monetary terms. These health effects are not quantified in this analysis.
Non-overlapping endpoints	Although the benefits associated with each individual health endpoint may be analyzed separately, care must be exercised in selecting health endpoints to include in the overall benefits analysis because of the possibility of double counting of benefits. Including emergency room visits in a benefits analysis that already considers hospital admissions, for example, will result in double counting of some benefits if the category "hospital admissions" includes emergency room visits.

Table 9A-19.
Endpoints and Studies Used to Calculate Total Monetized Health Benefits

Endpoint	**Pollutant**	**Study**	**Study Population**
Premature Mortality			
Base – Long-term exposure	$PM_{2.5}$	Krewski, et al. (2000)[A]	>29 years
Alternative – Short-term exposure[B]	$PM_{2.5}$	Schwartz et al. (1996) adjusted using ratio of distributed lag to single day coefficients from Schwartz et al. (2000)	all ages
Chronic Illness			
Chronic Bronchitis	$PM_{2.5}$	Abbey, et al. (1995)	> 26 years
Non-fatal Heart Attacks	$PM_{2.5}$	Peters et al. (2001)	Adults
Hospital Admissions			
Respiratory	Ozone	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp) Schwartz (1994a, 1994b) - ICD 480-486 (pneumonia) Moolgavkar et al. (1997) - ICD 480-487 (pneumonia) Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al (1997) - ICD 490-496 (COPD)	> 64 years
	Ozone	Burnett et al. (2001)	< 2 years
	$PM_{2.5}$	Pooled estimate: Moolgavkar (2000) - ICD 490-496 (COPD) Lippman et al. (2000) - ICD 490-496 (COPD)	> 64 years
	$PM_{2.5}$	Moolgavkar (2000) - ICD 490-496 (COPD)	20-64 years
	$PM_{2.5}$	Lippman et al. (2000) - ICD 480-486 (pneumonia)	> 64 years
	$PM_{2.5}$	Sheppard, et al. (1999) - ICD 493 (asthma)	< 65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2000) - ICD 390-429 (all cardiovascular) Lippman et al. (2000) - ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	> 64 years
	$PM_{2.5}$	Moolgavkar (2000) - ICD 390-429 (all cardiovascular)	20-64 years
Asthma-Related ER Visits	Ozone	Pooled estimate: Weisel et al. (1995), Cody et al. (1992), Stieb et al. (1996)	All ages
	$PM_{2.5}$	Norris et al. (1999)	0-18 years
Other Health Endpoints			
Acute Bronchitis	$PM_{2.5}$	Dockery et al. (1996)	8-12 years
Upper Respiratory Symptoms	PM_{10}	Pope et al. (1991)	Asthmatics, 9-11 years
Lower Respiratory Symptoms	$PM_{2.5}$	Pooled estimate: Schwartz et al. (1994); Schwartz and Neas (2000)	7-14 years
Work Loss Days	$PM_{2.5}$	Ostro (1987)	18-65 years
School Absence Days	Ozone	Pooled estimate: Gilliland et al (2001) Chen et al (2000)	 9-10 years 6-11 years
Worker Productivity	Ozone	Crocker and Horst (1981) and U.S. EPA (1984)	Outdoor workers, 18-65
Minor Restricted Activity Days	$PM_{2.5}$, Ozone	Ostro and Rothschild (1989)	18-65 years

[A] Estimate derived from Table 31, PM2.5(DC), All Causes Model (Relative Risk =1.12 for a 24.5 μg/m^3 increase in mean $PM_{2.5}$).

- Premature Mortality

Both long and short-term exposures to ambient levels of air pollution have been associated with increased risk of premature mortality. The size of the mortality risk estimates from these epidemiological studies, the serious nature of the effect itself, and the high monetary value ascribed to prolonging life make mortality risk reduction the most important health endpoint quantified in this analysis. Because of the importance of this endpoint and the considerable uncertainty among economists and policymakers as to the appropriate way to value reductions in mortality risks, both a base and an alternative estimate are provided. As in the Kunzli et al. (2000) analysis, we focus on the prospective cohort long-term exposure studies in deriving the C-R function for our base estimate of premature mortality.

Epidemiological analyses have consistently linked air pollution, especially PM, with excess mortality. Although a number of uncertainties remain to be addressed by continued research (NRC, 1998), a substantial body of published scientific literature documents the correlation between elevated PM concentrations and increased mortality rates. Community epidemiological studies that have used both short-term and long-term exposures and response have been used to estimate PM/ mortality relationships. Short-term studies use a time-series approach to relate short-term (often day-to-day) changes in PM concentrations and changes in daily mortality rates up to several days after a period of elevated PM concentrations. Long-term studies examine the potential relationship between community-level PM exposures over multiple years and community-level annual mortality rates. Researchers have found statistically significant associations between PM and premature mortality using both types of studies. In general, the risk estimates based on the long-term exposure studies are larger than those derived from short-term studies. Cohort analyses are better able to capture the full public health impact of exposure to air pollution over time (Kunzli, 2001; NRC, 2002). The alternative estimate is based on time-series studies demonstrating the effect of short-term exposures. This section discusses some of the issues surrounding the estimation of premature mortality.

Base Estimate

Over a dozen studies have found significant associations between various measures of long-term exposure to PM and elevated rates of annual mortality, beginning with Lave and Seskin, 1977. Most of the published studies found positive (but not always statistically significant) associations with available PM indices such as total suspended particles (TSP). Particles of different fine particles components (i.e. sulfates), and fine particles, as well as exploration of alternative model specifications sometimes found inconsistencies (e.g. Lipfert, 1989). These early "cross-sectional" studies (e.g. Lave and Seskin, 1977; Ozkaynak and Thurston, 1987) were criticized for a number of methodological limitations, particularly for inadequate control at the individual level for variables that are potentially important in causing mortality, such as wealth, smoking, and diet. More recently, several long-term studies have been published that use improved approaches and appear to be consistent with the earlier body of literature. These new "prospective cohort" studies reflect a significant improvement over the earlier work because they include individual-level information with respect to health status and residence. The most extensive study and analyses has been based on data from two prospective cohort groups, often referred to as the Harvard "Six-City study" (Dockery et al., 1993) and the

"American Cancer Society or ACS study" (Pope et al., 1995); these studies have found consistent relationships between fine particle indicators and premature mortality across multiple locations in the U.S. A third major data set comes from the California based 7th Day Adventist Study (e.g. Abbey et al, 1999), which reported associations between long-term PM exposure and mortality in men. Results from this cohort, however, have been inconsistent and the air quality results are not geographically representative of most of the US. More recently, a cohort of adult male veterans diagnosed with hypertension has been examined (Lipfert et al., 2000). The characteristics of this group differ from the cohorts in the ACS, Six-Cities, and 7th Day Adventist studies with respect to income, race, and smoking status. Unlike previous long-term analyses, this study found some associations between mortality and ozone but found inconsistent results for PM indicators.

Given their consistent results and broad geographic coverage, the Six-City and ACS data have been of particular importance in benefits analyses. The credibility of these two studies is further enhanced by the fact that they were subject to extensive reexamination and reanalysis by an independent team of scientific experts commisioned by the Health Effects Institute (Krewski et al., 2000). The final results of the reanalysis were then independently peer reviewed by a Special Panel of the HEI Health Review Committee. The results of these reanalyses confirmed and expanded those of the original investigators. This intensive independent reanalysis effort was occasioned both by the importance of the original findings as well as concerns that the underlying individual health effects information has never been made publicly available.

The HEI re-examination lends credibility to the original studies as well as highlighting sensitivities concerning (a) the relative impact of various pollutants, (b) the potential role of education in mediating the association between pollution and mortality, and (c) the influence of spatial correlation modeling. Further confirmation and extension of the overall findings using more recent air quality and a longer follow up period for the ACS cohort was recently published in the Journal of the American Medical Association (Pope et al., 2002).

In developing and improving the methods for estimating and valuing the potential reductions in mortality risk over the years, EPA has consulted with a panel of the Science Advisory Board. That panel recommended use of long-term prospective cohort studies in estimating mortality risk reduction (EPA-SAB-COUNCIL-ADV-99-005, 1999). This recommendation has been confirmed by a recent report from the National Research Council, which stated that "it is essential to use the cohort studies in benefits analysis to capture all important effects from air pollution exposure (NAS, 2002, p. 108)." More specifically, the SAB recommended emphasis on the ACS study because it includes a much larger sample size and longer exposure interval, and covers more locations (e.g. 50 cities compared to the Six Cities Study) than other studies of its kind. As explained in the regulatory impact analysis for the Heavy-Duty Engine/Diesel Fuel rule (U.S. EPA, 2000a), more recent EPA benefits analyses have relied on an improved specification of the ACS cohort data that was developed in the HEI reanalysis (Krewski et al., 2000). The particular specification yielded a relative risk based on changes in mean levels of $PM_{2.5}$, as opposed to the specification in the original study, which reported a relative risk based on median levels[r]. The Krewski et al analysis also includes a broader geographic scope than the original study (63 cities versus 50). Specifically, the relative risk from which the Base estimate is derived is 1.12 per 24.5 μg/m^3 for all-cause mortality (Krewski, et al. 2000, Part II, page 173, Table 31). The SAB has recently agreed with EPA's selection of this specification for use in analyzing mortality benefits of PM reductions (EPA-SAB-COUNCIL-ADV-01-004, 2001).

Alternative Estimate

To reflect concerns about the more limited number of cohort studies that examine the association between long-term exposure and mortality and the inherent limitations for drawing conclusions regarding causality from these studies, especially the ecological measure of exposure used, a plausible alternative to the base benefit estimate is provided. This estimate was derived from the larger number of time-series studies, the body of which have established a likely causal relationship between short-term measures of PM and daily mortality statistics. A particular strength of the design of these studies for drawing conclusions about causality is the fact that potential confounding variables such as socio-economic status, occupation, and smoking do not vary on a day-to-day basis in an individual area. A number of multi-city and other types of studies strongly suggest that these short term PM exposure-premature mortality relationships cannot be explained by weather, statistical approaches, or other pollutants.

The fact that the PM-mortality coefficients from the cohort studies are far larger than the coefficients derived from the daily time-series studies provides some evidence for an independent chronic effect of PM pollution on health. Indeed, the Base Estimate presumes that the larger coefficients represent a more complete accounting of mortality effects, including both the cumulative total of short-term mortality as well as an additional chronic effect. This is, however, not the only possible interpretation of the disparity. Various reviewers have argued that 1) the long-term estimates may be biased high and/or 2) the short-term estimates may be biased low. In this view, the two study types could be measuring the same underlying relationship.

With respect to possible sources of upward bias in the long-term studies, HEI reviewers have noted that the less robust estimates based on the Six-Cities Study are significantly higher than those based on the more broadly distributed ACS data sets. Some reviewers have also noted that the observed mortality associations from the 1980's and 90's may reflect higher pollution exposures from the 1950's to 1960's. Such an argument is consistent with the dramatic decrease in PM levels over the last 50 years, as long as the relative differences in PM among the cities did not change. Indeed, Pope et al (2002) demonstrated that the relative differences in pollution levels among the cities was similar between the years 1979-1980 and the years 1999-1980. If the lower PM exposures today pose disproportionately less risk than the exposures of the 1950's-

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[R] For policy analysis purposes, functions based on the mean air quality levels may be preferable to functions based on the median air quality levels because changes in the mean more accurately reflect changes in peak values than do changes in the median. Policies which affect peak PM days more than average PM days will result in a larger change in the mean than in the median. In these cases, all else being equal, C-R functions based on median $PM_{2.5}$ will lead to lower estimates of avoided incidences of premature mortality than C-R functions based on mean $PM_{2.5}$.

1960's, then the base mortality estimate may be biased upwards. While this would bias estimates based on more recent pollution levels upwards, it also would imply a truly long-term chronic effect of pollution, at least for the higher exposure levels.

With regard to possible sources of downward bias, it is of note that the recent studies suggest that the single day time series studies may understate the short-term effect on the order of a factor of two (Zanobetti et al, 2002). Previous daily mortality studies (Schwartz et al., 1996) examined the impact of $PM_{2.5}$ on mortality on a single day or over the average of two or more days. Although the risk estimates from the vast majority of the short-term studies include the effects of only one or two-day exposure to air pollution, more recently, several studies have found that the practice of examining the effects on a single day basis may significantly understate the risk of short-term exposures (Schwartz, 2000; Zanobetti et al, 2002). These studies suggest that the short-term risk can double when the single-day effects are combined with the cumulative impact of exposures over multiple days to weeks prior to a mortality event. Multi-day models are often referred to as "distributed lag" models because they assume that mortality following a PM event will be distributed over a number of days following or "lagging" the PM event. The size of the effect estimates from these models suggests consistency between the findings of studies that examine premature mortality impacts of short-term and long-term exposures. Additional research may be necessary to confirm this trend.

The United Kingdom’s Committee on the Medical Effects of Air Pollution’s evaluated the various models proposed by Krewski et al., 2000 (COMEAP 2001 Annual Report Annex C). In the judgment of the COMEAP, as published in it’s “Statement on the Long-term Effects of Particles on Mortality,” it is more appropriate to develop a “range of estimates along with comments on their confidence in them” than selecting a single estimate of possible effects. The inclusion of an Alternative Estimate, as well as the sensitivity analyses presented in Appendix 9B is an appropriate response to this suggestion.

These considerations provide a basis for considering an Alternative Estimate using the most recent estimates from the wealth of time-series studies, in addition to the Base Estimate based on the long-term cohort studies. In essence, the Alternative Estimate offers an approach to characterizing some of the uncertainties in the relationship between premature mortality and exposures to ambient levels of fine particles by assuming that there is no mortality effect of chronic exposures to fine particles. Instead, it assumes that the full impact of fine particles on premature mortality is captured using a concentration-response function relating daily mortality to short-term fine particle levels. This will clearly provide a lower bound to the mortality impacts of fine particle exposure, as it omits any additional mortality impacts from longer term exposures.

There are no $PM_{2.5}$ daily mortality studies which report numeric estimates of relative risks from distributed lag models; only PM_{10} studies are available. Daily mortality C-R functions for PM_{10} are consistently lower in magnitude than $PM_{2.5}$-mortality C-R functions, because fine particles are believed to be more closely associated with mortality than the coarse fraction of PM. Given that the emissions reductions under the Nonroad Diesel Engine program result primarily in reduced ambient concentrations of $PM_{2.5}$, use of a PM_{10} based C-R function results in a significant downward bias in the estimated reductions in mortality.

The Alternative Estimate is based on a concentration- response function derived from Schwartz et al. (1996), with an adjustment to account for recent evidence that daily mortality is associated with particle levels from a number of previous days (Schwartz, 2000). Specifically, to account for the full potential multi-day mortality impact of acute $PM_{2.5}$ events, we use the distributed lag model for PM_{10} reported in Schwartz (2000) to develop an adjustment factor which we then apply to the $PM_{2.5}$ based C-R function reported in Schwartz et al. (1996).

If most of the increase in mortality is expected to be associated with the fine fraction of PM_{10}, then it is reasonable to assume that the same proportional increase in risk would be observed if a distributed lag model were applied to the $PM_{2.5}$ data. The distributed lag adjustment factor is constructed as the ratio of the estimated coefficient from the unconstrained distributed lag model to the estimated coefficient from the single-lag model reported in Schwartz (2000). The unconstrained distributed lag model coefficient estimate is 0.0012818 and the single-lag model coefficient estimate is 0.0006479. The ratio of these estimates is 1.9784. This adjustment factor is then multiplied by the estimated coefficients from the Schwartz et al. (1996) study. There are two relevant coefficients from the Schwartz et al. (1996) study, one corresponding to all-cause mortality, and one corresponding to chronic obstructive pulmonary disease (COPD) mortality (separation by cause is necessary to implement the life years lost approach detailed below). The adjusted estimates for these two C-R functions are:

All cause mortality = $0.001489 * 1.9784 = 0.002946$

COPD mortality = $0.003246 * 1.9784 = 0.006422$

Note that these estimates, while approximating the full impact of daily pollution levels on daily death counts, do not capture any impacts of long-term exposure to air pollution. As discussed earlier, EPA's Science Advisory Board, while acknowledging the uncertainties in estimation of a PM-mortality relationship, has repeatedly recommended the use of a study that does reflect the impacts of long-term exposure. This recommendation has been confirmed by the recent NRC report on estimating health benefits of air pollution regulations. The omission of long-term impacts accounts for approximately a 40 percent reduction in the estimate of avoided premature mortality in the Alternative Estimate relative to the Base Estimate. For comparison, an estimate calculated using the lower confidence interval of the Base estimate C-R function coefficient would fall between these two estimates (i.e., the lower confidence interval on the RR of 1.12 used in the Base Estimate is 1.06, translating to a coefficient estimate of 0.002).[s] In

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[S] The 40% smaller estimate is also consistent with a judgment offered by COMEAP based on its review of the use of U.S. cohort studies in a European context. The alternative estimate of premature mortality is similar in magnitude to their judgement of a “likely” estimate, based on a sensitivity analysis included in the Krewski et al (2000) reanalysis of the ACS cohort data. That sensitivity analysis was based on a much smaller set of cities and included SO2 and other variables as controls. In addition to PM2.5, this specification found a significant impact of SO2 on mortality. SO2 and PM2.5 levels are at least somewhat correlated, so it is not clear in a multi-pollutant summary, the alternative estimate has a technical foundation in both a plausible interpretation of the cohort studies and the time-series studies that incorporate the longer lag periods .

- Chronic bronchitis

Chronic bronchitis is characterized by mucus in the lungs and a persistent wet cough for at least three months a year for several years in a row. Chronic bronchitis affects an estimated five percent of the U.S. population (American Lung Association, 1999). There are a limited number of studies that have estimated the impact of air pollution on new incidences of chronic bronchitis. Schwartz (1993) and Abbey, et al.(1995) provide evidence that long-term PM exposure gives rise to the development of chronic bronchitis in the U.S. Because the nonroad standards are expected to reduce primarily $PM_{2.5}$, this analysis uses only the Abbey et al (1995) study, because it is the only study focusing on the relationship between $PM_{2.5}$ and new incidences of chronic bronchitis.

- Non-fatal myocardial infarctions (heart attacks)

Non-fatal heart attacks have been linked with short term exposures to PM2.5 in the U.S. (Peters et al. 2001) and other countries (Poloniecki et al. 1997). We use a recent study by Peters et al. (2001) as the basis for the C-R function estimating the relationship between PM2.5 and non-fatal heart attacks. Peters et al. is the only available U.S. study to provide a specific estimate for heart attacks. Other studies, such as Samet et al. (2000) and Moolgavkar et al. (2000) show a consistent relationship between all cardiovascular hospital admissions, including for non-fatal heart attacks, and PM. Given the lasting impact of a heart attack on longer-term health costs and earnings, we choose to provide a separate estimate for non-fatal heart attacks based on the single available U.S. C-R function. The finding of a specific impact on heart attacks is consistent with hospital admission and other studies showing relationships between fine particles and cardiovascular effects both within and outside the U.S. These studies provide a weight of evidence for this type of effect. Several epidemiologic studies (Liao et al, 1999; Gold et al, 2000; Magari et al, 2001) have shown that heart rate variability (an indicator of how much the heart is able to speed up or slow down in response to momentary stresses) is negatively related to PM levels. Heart rate variability is a risk factor for heart attacks and other coronary heart diseases (Carthenon et al, 2002; Dekker et al, 2000; Liao et al, 1997, Tsuji et al. 1996). As such, significant impacts of PM on heart rate variability is consistent with an increased risk of heart attacks.

- Hospital and emergency room admissions

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specification how much of the SO2 effect is capturing some of the PM2.5 signal and vice versa. An appropriate comparison would be between the COMEAP estimate and the total mortality impact of the nonroad rule predicted using both the PM2.5 and SO2 changes. Comparing PM2.5 related mortality generated from a single pollutant mortality function with a multi-pollutant specification ignores the implied benefits of SO2 reductions under the rule. Thus it is likely that the COMEAP estimate would understate the total mortality impacts likely to be associated with the proposed nonroad rule.

Due to the availability of detailed hospital admission and discharge records, there is an extensive body of literature examining the relationship between hospital admissions and air pollution. Because of this, many of the hospital admission endpoints will use pooled C-R functions based on the results of a number of studies. In addition, some studies have examined the relationship between air pollution and emergency room (ER) visits. Because most ER visits do not result in an admission to the hospital (the majority of people going to the ER are treated and return home) we treat hospital admissions and ER visits separately, taking account of the fraction of ER visits that are admitted to the hospital.

Hospital admissions require the patient to be examined by a physician, and on average may represent more serious incidents than ER visits. The two main groups of hospital admissions estimated in this analysis are respiratory admissions and cardiovascular admissions. There is not much evidence linking ozone or PM with other types of hospital admissions. The only type of ER visits that have been consistently linked to ozone and PM in the U.S. are asthma-related visits.

To estimate avoided incidences of cardiovascular hospital admissions associated with PM2.5, we use studies by Moolgavkar (2000) and Lippmann et al (2000). There are additional published studies showing a statistically significant relationship between PM10 and cardiovascular hospital admissions. However, given that the preliminary control options we are analyzing are expected to reduce primarily PM2.5, we have chosen to focus on the two studies focusing on PM2.5. Both of these studies estimated a C-R function for populations over 65, allowing us to pool the C-R functions for this age group. Only Moolgavkar (2000) estimated a separate C-R function for populations 20 to 64. Total cardiovascular hospital admissions are thus the sum of the pooled estimate for populations over 65 and the single study estimate for populations 20 to 64. Cardiovascular hospital admissions include admissions for myocardial infarctions. In order to avoid double counting benefits from reductions in MI when applying the C-R function for cardiovascular hospital admissions, we first adjusted the baseline cardiovascular hospital admissions to remove admissions for MI.

To estimate total avoided incidences of respiratory hospital admissions, we use C-R functions for several respiratory causes, including chronic obstructive pulmonary disease (COPD), pneumonia, and asthma. As with cardiovascular admissions, there are additional published studies showing a statistically significant relationship between PM10 and respiratory hospital admissions. We use only those focusing on PM2.5. Both Moolgavkar (2000) and Lippmann et al (2000) estimated C-R functions for COPD in populations over 65, allowing us to pool the C-R functions for this group. Only Moolgavkar (2000) estimated a separate C-R function for populations 20 to 64. Total COPD hospital admissions are thus the sum of the pooled estimate for populations over 65 and the single study estimate for populations 20 to 64. Only Lippmann et al (2000) estimated pneumonia, and only for the population 65 and older. In addition, Sheppard, et al. (1999) estimated a C-R function for asthma hospital admissions for populations under age 65. Total avoided incidences of PM-related respiratory-related hospital admissions is the sum of COPD, pneumonia, and asthma admissions.

To estimate the effects of PM air pollution reductions on asthma-related ER visits, we use the C-R function based on a study of children 18 and under by Norris et al. (1999). As noted earlier, there is another study by Schwartz examining a broader age group (less than 65), but the Schwartz study focused on PM10 rather than PM2.5. We selected the Norris et al. (1999) C-R function because it better matched the pollutant of interest. Because children tend to have higher rates of hospitalization for asthma relative to adults under 65, we will likely capture the majority of the impact of PM2.5 on asthma ER visits in populations under 65, although there may still be significant impacts in the adult population under 65. Because we are estimating ER visits as well as hospital admissions for asthma, we must avoid counting twice the ER visits for asthma that are subsequently admitted to the hospital. To avoid double-counting, the baseline incidence rate for ER visits is adjusted by subtracting the percentage of patients that are admitted into the hospital.

To estimate avoided incidences of respiratory hospital admissions associated with ozone, we use a number of studies examining hospital admissions for a range of respiratory illnesses, including pneumonia and COPD. Two age groups, adults over 65 and children under 2, are examined. For adults over 65, Schwartz (1995) provides C-R functions for 2 different cities relating ozone and hospital admissions for all respiratory causes (defined as ICD codes 460-519). These C-R functions are pooled first before being pooled with other studies. Two studies (Moolgavkar et al., 1997; Schwartz, 1994a) examined ozone and pneumonia hospital admissions in Minneapolis. One additional study (Schwartz, 1994b) examined ozone and pneumonia hospital admissions in Detroit. The C-R functions for Minneapolis are pooled together first, and the resulting C-R function is then pooled with the C-R function for Detroit. This avoids assigning too much weight to the information coming from one city. For COPD hospital admissions, there are two available studies, Moolgavkar et al. (1997), conducted in Minneapolis, and Schwartz (1994b), conducted in Detroit. These two studies are pooled together. In order to estimate total respiratory hospital admissions for adults over 65, COPD admissions are added to pneumonia admissions, and the result is pooled with the Schwartz (1995) estimate of total respiratory admissions. Burnett et al. (2001), is the only study providing a C-R function for respiratory hospital admissions in children under two.

- Minor Illnesses, Restricted Activity Days, and School/Work Loss Days

As indicated in Table 9A-1, in addition to mortality, chronic illness, and hospital admissions, there are a number of acute health effects not requiring hospitalization that are associated with exposure to ambient levels of ozone and PM. The sources for the C-R functions used to quantify these effects are described below.

Around four percent of U.S. children between ages five and seventeen experience episodes of acute bronchitis annually (American Lung Association, 2002). Acute bronchitis is characterized by coughing, chest discomfort, slight fever, and extreme tiredness, lasting for a number of days. According to the MedlinePlus medical encyclopedia[t], with the exception of

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[T] See http://www.nlm.nih.gov/medlineplus/ency/article/000124.htm, accessed January 2002 cough, most acute bronchitis symptoms abate within 7 to 10 days. Incidence of episodes of acute bronchitis in children between the ages of five and seventeen are estimated using a C-R function developed from Dockery, et al. (1996).

Incidences of lower respiratory symptoms (i.e., wheezing, deep cough) in children aged seven to fourteen are estimated using a C-R function developed from Schwartz, et al. (1994).

Because asthmatics have greater sensitivity to stimuli (including air pollution), children with asthma can be more susceptible to a variety of upper respiratory symptoms (i.e., runny or stuffy nose; wet cough; and burning, aching, or red eyes). Research on the effects of air pollution on upper respiratory symptoms have thus focused on effects in asthmatics. Incidences of upper respiratory symptoms in asthmatic children aged nine to eleven are estimated using a C-R function developed from Pope, et al. (1991).

Health effects from air pollution can also result in missed days of work (either from personal symptoms or from caring for a sick family member). Work loss days due to PM2.5 are estimated using a C-R function developed from Ostro (1987). Children may also be absent from school due to respiratory or other diseases caused by exposure to air pollution. Most studies examining school absence rates have found little or no association with PM2.5, but several studies have found a significant association between ozone levels and school absence rates. We use two recent studies, Gilliland et al. (2001) and Chen et al. (2000) to estimate changes in absences (school loss days) due to changes in ozone levels. The Gilliland et al. study estimated the incidence of new periods of absence, while the Chen et al. study examined absence on a given day. We convert the Gilliland estimate to days of absence by multiplying the absence periods by the average duration of an absence. We estimate an average duration of school absence of 1.6 days by dividing the average daily school absence rate from Chen et al. (2000) and Ransom and Pope (1992) by the episodic absence rate from Gilliland et al. (2001). This provides estimates from Chen et al. (2000) and Gilliland et al. (2000) which can be pooled to provide an overall estimate.

Minor restricted activity days (MRAD) result when individuals reduce most usual daily activities and replace them with less strenuous activities or rest, yet not to the point of missing work or school. For example, a mechanic who would usually be doing physical work most of the day, will instead spend the day at a desk doing paper and phone work due to difficulty breathing or chest pain. The effect of PM2.5 and ozone on MRAD is estimated using a C-R function derived from Ostro and Rothschild (1989).

The Agency is currently evaluating how air pollution related symptoms in the asthmatic population should be incorporated into the overall benefits analysis. Clearly, studies of the general population also include asthmatics, so estimates based solely on the asthmatic population cannot be directly added to the general population numbers without double-counting. In one specific case, upper respiratory symptoms in children, the only study available was limited to asthmatic children, so this endpoint is included in the calculation of total benefits. However, other endpoints, such as lower respiratory symptoms, are estimated for the total population of children. Given the increased susceptibility of the asthmatic population, it is of interest to understand better the specific impacts on asthmatics. We are providing a separate set of estimated health impacts for asthmatic populations, listed it Table 9A-20, with the caveat that these are not additive, nor can they be easily combined with other endpoints to derive total benefits. They are provided only to highlight the potential impacts on a susceptible population.

Table 9A.20.
Studies Examining Health Impacts in the Asthmatic Population

Endpoint	**Definition**	**Pollutant**	**Study**	**Study Population**
Asthma Attack Indicators[1]				
Shortness of Breath	prevalence of shortness of breath; incidence of shortness of breath	$PM_{2.5}$	Ostro et al. (2001)	African American asthmatics, 8-13
Cough	prevalence of cough; incidence of cough	$PM_{2.5}$	Ostro et al. (2001)	African American asthmatics, 8-13
Wheeze	prevalence of wheeze; incidence of wheeze	$PM_{2.5}$	Ostro et al. (2001)	African American asthmatics, 8-13
Asthma Exacerbation	≥1 mild asthma symptom: wheeze, cough, chest tightness, shortness of breath)	PM_{10}, $PM_{1.0}$	Yu et al. (2000)	Asthmatics, 5-13
Cough	prevalence of cough	PM_{10}	Vedal et al. (1998)	Asthmatics, 6-13
Other symptoms/illness endpoints				
Upper Respiratory Symptoms	≥1 of the following: runny or stuffy nose; wet cough; burning, aching, or red eyes	PM_{10}	Pope et al. (1991)	Asthmatics 9-11
Moderate or Worse Asthma	probability of moderate (or worse) rating of overall asthma status	$PM_{2.5}$	Ostro et al. (1991)	Asthmatics, all ages
Acute Bronchitis	≥1 episodes of bronchitis in the past 12 months	$PM_{2.5}$	McConnell et al. (1999)	Asthmatics, 9-15*
Phlegm	"other than with colds, does this child usually seem congested in the chest or bring up phlegm?"	$PM_{2.5}$	McConnell et al. (1999)	Asthmatics, 9-15*
Asthma Attacks	respondent-defined asthma attack	PM2.5, ozone	Whittemore and Korn (1980)	Asthmatics, all ages

9A.3.5.2 Uncertainties Associated with Concentration-Response Functions

Within-Study Variation

Within-study variation refers to the precision with which a given study estimates the relationship between air quality changes and health effects. Health effects studies provide both a "best estimate" of this relationship plus a measure of the statistical uncertainty of the relationship. This size of this uncertainty depends on factors such as the number of subjects studied and the size of the effect being measured. The results of even the most well-designed epidemiological studies are characterized by this type of uncertainty, though well-designed studies typically report narrower uncertainty bounds around the best estimate than do studies of lesser quality. In selecting health endpoints, we generally focus on endpoints where a statistically significant relationship has been observed in at least some studies, although we may pool together results from studies with both statistically significant and insignificant estimates to avoid selection bias.

Across-study Variation

Across-study variation refers to the fact that different published studies of the same pollutant/health effect relationship typically do not report identical findings; in some instances the differences are substantial. These differences can exist even between equally reputable studies and may result in health effect estimates that vary considerably. Across-study variation can result from two possible causes. One possibility is that studies report different estimates of the single true relationship between a given pollutant and a health effect due to differences in study design, random chance, or other factors. For example, a hypothetical study conducted in New York and one conducted in Seattle may report different C-R functions for the relationship between PM and mortality, in part because of differences between these two study populations (e.g., demographics, activity patterns). Alternatively, study results may differ because these two studies are in fact estimating different relationships; that is, the same reduction in PM in New York and Seattle may result in different reductions in premature mortality. This may result from a number of factors, such as differences in the relative sensitivity of these two populations to PM pollution and differences in the composition of PM in these two locations. In either case, where we identified multiple studies that are appropriate for estimating a given health effect, we generated a pooled estimate of results from each of those studies.

Application of C-R Relationship Nationwide

Whether this analysis estimated the C-R relationship between a pollutant and a given health endpoint using a single function from a single study or using multiple C-R functions from several studies, each C-R relationship was applied uniformly throughout the U.S. to generate health benefit estimates. However, to the extent that pollutant/health effect relationships are region-specific, applying a location-specific C-R function at all locations in the U.S. may result in overestimates of health effect changes in some locations and underestimates of health effect changes in other locations. It is not possible, however, to know the extent or direction of the overall effect on health benefit estimates introduced by application of a single C-R function to the entire U.S. This may be a significant uncertainty in the analysis, but the current state of the scientific literature does not allow for a region-specific estimation of health benefits[u].

Extrapolation of C-R Relationship Across Populations

Epidemiological studies often focus on specific age ranges, either due to data availability limitations (for example, most hospital admission data comes from Medicare records, which are

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[U] Although we are not able to use region-specific C-R functions, we use region-specific baseline incidence rates where available. This allows us to take into account regional differences in health status, which can have a significant impact on estimated health benefits.

limited to populations 65 and older), or to simplify data collection (for example, some asthma symptom studies focus on children at summer camps, which usually have a limited age range). We have assumed for the primary analysis that C-R functions should be applied only to those population with ages that strictly match the populations in the underlying epidemiological studies. In many cases, there is no biological reason why the observed health effect would not also occur in other populations within a reasonable range of the studied population. For example, Dockery et al. (1996) examined acute bronchitis in children aged 8 to 12. There is no biological reason to expect a very different response in children aged 6 or 14. By excluding populations outside the range in the studies, we may be underestimating the health impact in the overall population. We provide a set of expanded incidence estimates to show the effect of this assumption.

Uncertainties in the PM Mortality Relationship

Health researchers have consistently linked air pollution, especially PM, with excess mortality. A substantial body of published scientific literature recognizes a correlation between elevated PM concentrations and increased mortality rates. However, there is much about this relationship that is still uncertain. These uncertainties include:

- Causality. A substantial number of published epidemiological studies recognize a correlation between elevated PM concentrations and increased mortality rates; however these epidemiological studies, by design, can not definitively prove causation. For the analysis of the Nonroad Diesel Engine rulemaking, we assumed a causal relationship between exposure to elevated PM and premature mortality, based on the consistent evidence of a correlation between PM and mortality reported in the substantial body of published scientific literature.

- Other Pollutants. PM concentrations are correlated with the concentrations of other criteria pollutants, such as ozone and CO, and it is unclear how much each of these pollutants may influence mortality rates. Recent studies (see Thurston and Ito, 2001) have explored whether ozone may have mortality effects independent of PM, but we do not view the evidence as conclusive at this time. To the extent that the C-R functions we use to evaluate the preliminary control options in fact capture mortality effects of other criteria pollutants besides PM, we may be overestimating the benefits of reductions in PM. However, we are not providing separate estimates of the mortality benefits from the ozone and CO reductions likely to occur due to the preliminary control options.

- Shape of the C-R Function. The shape of the true PM mortality C-R function is uncertain, but this analysis assumes the C-R function to have a log-linear form (as derived from the literature) throughout the relevant range of exposures. If this is not the correct form of the C-R function, or if certain scenarios predict concentrations well above the range of values for which the C-R function was fitted, avoided mortality may be mis-estimated.

- Regional Differences. As discussed above, significant variability exists in the results of different PM/mortality studies. This variability may reflect regionally-specific C-R functions resulting from regional differences in factors such as the physical and chemical composition of PM. If true regional differences exist, applying the PM/Mortality C-R function to regions outside the study location could result in mis-estimation of effects in these regions.

- Exposure/Mortality Lags. There is a potential time lag between changes in PM exposures and changes in mortality rates. For the chronic PM/mortality relationship, the length of the lag is unknown and may be dependent on the kind of exposure. The existence of such a lag is important for the valuation of premature mortality incidence because economic theory suggests that benefits occurring in the future should be discounted. There is no specific scientific evidence of the existence or structure of a PM effects lag. However, current scientific literature on adverse health effects similar to those associated with PM (e.g., smoking-related disease) and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure probably would not occur in the same year as the exposure reduction. The smoking-related literature also implies that lags of up to a few years or longer are plausible. Adopting the lag structure used in the Tier 2/Gasoline Sulfur and Heavy-Duty Engine/Diesel Fuel RIAs and endorsed by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), we assume a five-year lag structure. This approach assumes that 25 percent of PM-related premature deaths occur in each of the first two years after the exposure and the rest occur in equal parts (approximately 17%) in each of the ensuing three years.

- Cumulative Effects. As a general point, we attribute the PM/mortality relationship in the underlying epidemiological studies to cumulative exposure to PM. However, the relative roles of PM exposure duration and PM exposure level in inducing premature mortality remain unknown at this time.

9A.3.5.3 Baseline Health Effect Incidence Rates

The epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the relative risk of a health effect, rather than an estimate of the absolute number of avoided cases. For example, a typical result might be that a 10 $\mu g/m^3$ decrease in daily $PM_{2.5}$ levels might decrease hospital admissions by three percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. The baseline incidence rate provides an estimate of the incidence rate (number of cases of the health effect per year, usually per 10,000 or 100,000 general population) in the assessment location corresponding to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number (e.g., if the baseline incidence rate is number of cases per year per 100,000 population, it must be multiplied by the number of 100,000s in the population).

Some epidemiological studies examine the association between pollution levels and adverse health effects in a specific subpopulation, such as asthmatics or diabetics. In these cases, it is necessary to develop not only baseline incidence rates, but also prevalence rates for the defining condition, i.e. asthma. For both baseline incidence and prevalence data, we use age-specific rates where available. Concentration-response functions are applied to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits.

In most cases, due to a lack of data or methods, we have not attempted to project incidence rates to future years, instead assuming that the most recent data on incidence rates is the best prediction of future incidence rates. In recent years, better data on trends in incidence and prevalence rates for some endpoints, such as asthma, have become available. We are working to develop methods to use these data to project future incidence rates. However, for our primary benefits analysis of the proposed nonroad rule, we will continue to use current incidence rates. We will examine the impact of using projected mortality rates and asthma prevalence in sensitivity analyses.

Table 9A-2 summarizes the baseline incidence data and sources used in the benefits analysis. In most cases, a single national incidence rate is used, due to a lack of more spatially disaggregated data. We used national incidence rates whenever possible, because these data are most applicable to a national assessment of benefits. However, for some studies, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. However, for hospital admissions, regional rates are available, and for premature mortality, county level data are available.

Age, cause, and county-specific mortality rates were obtained from the U.S. Centers for Disease Control (CDC) for the years 1996 through 1998. CDC maintains an online data repository of health statistics, CDC Wonder, accessible at http://wonder.cdc.gov/. The mortality rates provided are derived from U.S. death records and U.S. Census Bureau postcensal population estimates. Mortality rates were averaged across three years (1996 through 1998) to provide more stable estimates. When estimating rates for age groups that differed from the CDC Wonder groupings, we assumed that rates were uniform across all ages in the reported age group. For example, to estimate mortality rates for individuals ages 30 and up, we scaled the 25-34 year old death count and population by one-half and then generated a population-weighted mortality rate using data for the older age groups.

For the set of endpoints affecting the asthmatic population, in addition to baseline incidence rates, prevalence rates of asthma in the population are needed to define the applicable population. Table 9A-21 lists the baseline incidence rates and their sources for asthma symptom endpoints. Table 9A-22 lists the prevalence rates used to determine the applicable population for asthma symptom endpoints. Note that these reflect current asthma prevalence and assume no change in prevalence rates in future years. As noted above, we are investigating methods for projecting asthma prevalence rates in future years.

Table 9A-21.
Baseline Incidence Rates and Population Prevalence Rates for Use in C-R Functions, General Population

Endpoint	Parameter	Rates	
		Value	Source[1]
Mortality	Daily or annual mortality rate	Age, cause, and county-specific rate	CDC Wonder (1996-1998)
Hospitalizations	Daily hospitalization rate	Age, region, cause-specific rate	1999 NHDS public use data files[2]
Asthma ER visits	Daily asthma ER visit rate	Age, Region specific visit rate	2000 NHAMCS public use data files[3]; 1999 NHDS public use data files[2]
Chronic Bronchitis	Annual prevalence rate per person Age 18-44 Age 45-64 Age 65 and older	 0.0367 0.0505 0.0587	1999 HIS (American Lung Association, 2002b, Table 4)
	Annual incidence rate per person	0.00378	Abbey et al. (1993, Table 3)
Nonfatal MI (heart attacks)	Daily nonfatal myocardial infarction incidence rate per person, 18+ Northeast Midwest South West	 0.0000159 0.0000135 0.0000111 0.0000100	1999 NHDS public use data files[2]; adjusted by 0.93 for prob. of surviving after 28 days (Rosamond et al., 1999)
Acute Bronchitis	Annual bronchitis incidence rate, children	0.043	American Lung Association (2002a, Table 11)
Lower Respiratory Symptoms	Daily lower respiratory symptom incidence among children[4]	0.0012	Schwartz (1994, Table 2)
Upper Respiratory Symptoms	Daily upper respiratory symptom incidence among asthmatic children	0.3419	Pope et al. (1991, Table 2)
Work Loss Days	Daily WLD incidence rate per person (18-65) Age 18-24 Age 25-44 Age 45-64	 0.00540 0.00678 0.00492	1996 HIS (Adams et al., 1999, Table 41); U.S. Bureau of the Census (2000)
Minor Restricted Activity Days	Daily MRAD incidence rate per person	0.02137	Ostro and Rothschild (1989, p. 243)
School Loss Days[5]	Daily school absence rate per person	0.055	National Center for Education Statistics (1996)
	Daily illness-related school absence rate per person[5] Northeast Midwest South Southwest	 0.0136 0.0146 0.0142 0.0206	1996 HIS (Adams et al., 1999, Table 47); estimate of 180 school days per year

Endpoint	Parameter	Rates	
		Value	Source[1]
	Daily *respiratory* illness-related school absence rate per person		1996 HIS (Adams et al., 1999, Table 47); estimate of 180 school days per year
	Northeast	0.0073	
	Midwest	0.0092	
	South	0.0061	
	West	0.0124	

1. The following abbreviations are used to describe the national surveys conducted by the National Center for Health Statistics: HIS refers to the National Health Interview Survey; NHDS - National Hospital Discharge Survey; NHAMCS - National Hospital Ambulatory Medical Care Survey.
2. See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/
3. See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/
4. Lower Respiratory Symptoms are defined as ≥2 of the following: cough, chest pain, phlegm, wheeze
5. The estimate of daily illness-related school absences excludes school loss days associated with injuries to match the definition in the Gilliland et al. (2001) study.

Table 9A-22.
Baseline Incidence Rates and Population Prevalence Rates of Asthma Symptoms for use in C-R Functions, Asthmatic Population.

Endpoint	Parameter	Rates	
		Value	Source[1]
Asthma Exacerbation, wheeze	Daily wheeze incidence among asthmatic children (African-American)	0.076	Ostro et al. (2001, p. 202)
	Daily wheeze prevalence among asthmatic children (African-American)	0.173	Ostro et al. (2001, p. 202)
	Daily wheeze prevalence among asthmatic children	0.038	Vedal et al. (1998, Table 1)
Asthma Exacerbation, cough	Daily cough incidence among asthmatic children (African-American)	0.067	Ostro et al. (2001, p. 202)
	Daily cough prevalence among asthmatic children (African-American)	0.145	Ostro et al. (2001, p. 202)
	Daily cough prevalence among asthmatic children	0.086	Vedal et al. (1998, Table 1)
Asthma Exacerbation, dyspnea	Daily dyspnea incidence among asthmatic children (African-American)	0.037	Ostro et al. (2001, p. 202)
	Daily dyspnea prevalence among asthmatic children (African-American)	0.074	Ostro et al. (2001, p. 202)
	Daily dyspnea prevalence among asthmatic children	0.045	Vedal et al. (1998, Table 1)
Asthma Exacerbation, one or more	Daily prevalence among asthmatic children of at least one of the following symptoms: wheeze, cough, chest tightness, shortness of breath.	0.60	Yu et al. (2000, Table 2)
Asthma Attacks	Daily incidence of asthma attacks	0.055	HIS 1999
Acute/Chronic Bronchitis	Annual bronchitis incidence rate among asthmatic children	0.326	McConnell et al.(1999, Table 2)
Chronic Phlegm	Annual phlegm incidence rate among asthmatic children	0.257	McConnell et al.(1999, Table 2)
Upper Respiratory Symptoms	Daily upper respiratory symptom incidence among asthmatic children*	0.3419	Pope et al. (1991, Table 2)

1. The following abbreviations are used to describe the national surveys conducted by the National Center for Health Statistics: HIS refers to the National Health Interview Survey; NHDS - National Hospital Discharge Survey; NHAMCS - National Hospital Ambulatory Medical Care Survey.

* Upper Respiratory Symptoms are defined as ≥1 of the following: runny or stuffy nose; wet cough; burning, aching, or red eyes.

Table 9A-24.
Asthma Prevalence Rates Used to Estimate Asthmatic Populations in C-R Functions

Population Group	Asthma Prevalence Rates	
	Value	Source
All Ages	0.0386	American Lung Association (2002c, Table 7)- based on 1999 HIS
<18	0.0527	American Lung Association (2002c, Table 7)- based on 1999 HIS
5-17	0.0567	American Lung Association (2002c, Table 7)- based on 1999 HIS
18-44	0.0371	American Lung Association (2002c, Table 7)- based on 1999 HIS
45-64	0.0333	American Lung Association (2002c, Table 7)- based on 1999 HIS
65+	0.0221	American Lung Association (2002c, Table 7)- based on 1999 HIS
Male, 27+	0.021	2000 HIS public use data files[1]
African-American, 5 to 17	0.0726	American Lung Association (2002c, Table 9)- based on 1999 HIS
African-American, <18	0.0735	American Lung Association (2002c, Table 9)- based on 1999 HIS

1. See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/HIS/2000/

9A.3.5.4 Accounting for Potential Health Effect Thresholds

When conducting clinical (chamber) and epidemiological studies, C-R functions may be estimated with or without explicit thresholds. Air pollution levels below the threshold are assumed to have no associated adverse health effects. When a threshold is not assumed, as is often the case in epidemiological studies, any exposure level is assumed to pose a non-zero risk of response to at least one segment of the population.

The possible existence of an effect threshold is a very important scientific question and issue for policy analyses such as this one. The EPA Science Advisory Board Advisory Council for Clean Air Compliance, which provides advice and review of EPA's methods for assessing the benefits and costs of the Clean Air Act under Section 812 of the Clean Air Act, has advised EPA that there is currently no scientific basis for selecting a threshold of 15 $\mu g/m^3$ or any other specific threshold for the PM-related health effects considered in typical benefits analyses (EPA-SAB-Council-ADV-99-012, 1999). This is supported by the recent literature on health effects of PM exposure (Daniels et al., 2000; Pope, 2000; Rossi et al., 1999; Schwartz, 2000) which finds in most cases no evidence of a non-linear concentration-response relationship and certainly does not find a distinct threshold for health effects. The most recent draft of the EPA Air Quality Criteria for Particulate Matter (U.S. EPA, 2002) reports only one study, analyzing data from

Phoenix, AZ, that reported even limited evidence suggestive of a possible threshold for PM2.5 (Smith et al., 2000).

Recent cohort analyses by the Health Effects Institute (Krewski et al., 2000) and Pope et al. (2002) provide additional evidence of a quasi-linear concentration-response relationship between long-term exposures to $PM_{2.5}$ and mortality. According to the latest draft PM criteria document, Krewski et al. (2000) "found a visually near-linear relationship between all-cause and cardiopulmonary mortality residuals and mean sulfate concentrations, near-linear between cardiopulmonary mortality and mean $PM_{2.5}$, but a somewhat nonlinear relationship between all-cause mortality residuals and mean $PM_{2.5}$ concentrations that flattens above about 20 µg/m_3. The confidence bands around the fitted curves are very wide, however, neither requiring a linear relationship nor precluding a nonlinear relationship if suggested by reanalyses." The Pope et al. (2002) analysis, which represented an extension to the Krewski et al. analysis, found that the concentration-response relationships relating PM2.5 and mortality "were not significantly different from linear associations."

Daniels et al. (2000) examined the presence of threshold in PM_{10} concentration-response relationships for daily mortality using the largest 20 U.S. cities for 1987-1994. The results of their models suggest that the linear model was preferred over spline and threshold models. Thus, these results suggest that linear models without a threshold may well be appropriate for estimating the effects of PM_{10} on the types of mortality of main interest. Schwartz and Zanobetti (2000) investigated the presence of threshold by simulation and actual data analysis of 10 U.S. cities. In the analysis of real data from 10 cities, the combined concentration-response curve did not show evidence of a threshold in the PM_{10}-mortality associations. Schwartz, Laden, and Zanobetti (2002) investigated thresholds by combining data on the PM2.5-mortality relationships for six cities and found an essentially linear relationship down to 2 µg/m^3, which is at or below anthropogenic background in most areas. They also examined just traffic related particles and again found no evidence of a threshold. The Smith et al. (2000) study of associations between daily total mortality and $PM_{2.5}$ and $PM_{10-2.5}$ in Phoenix, AZ (during 1995-1997) also investigated the possibility of a threshold using a piecewise linear model and a cubic spline model. For both the piecewise linear and cubic spline models, the analysis suggested a threshold of around 20 to 25 µg/m^3. However, the concentration-response curve for $PM_{2.5}$ presented in this publication suggests more of a U- or V-shaped relationship than the usual "hockey stick" threshold relationship.

Based on the recent literature and advice from the SAB, we assume there are no thresholds for modeling health effects. Although not included in the primary analysis, the potential impact of a health effects threshold on avoided incidences of PM-related premature mortality is explored as a key sensitivity analysis and is presented in Appendix 9-B.

Our assumptions regarding thresholds are supported by the National Research Council in its recent review of methods for estimating the public health benefits of air pollution regulations. In their review, the National Research Council concluded that there is no evidence for any departure from linearity in the observed range of exposure to PM_{10} or $PM_{2.5}$, nor any indication of a threshold. They cite the weight of evidence available from both short and long term exposure models and the similar effects found in cities with low and high ambient concentrations of PM.

9A.3.5.5 Selecting Unit Values for Monetizing Health Endpoints

The appropriate economic value of a change in a health effect depends on whether the health effect is viewed ex ante (before the effect has occurred) or ex post (after the effect has occurred). Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health affects by a fairly small amount for a large population. The appropriate economic measure is therefore ex ante WTP for changes in risk. However, epidemiological studies generally provide estimates of the relative risks of a particular health effect avoided due to a reduction in air pollution. A convenient way to use this data in a consistent framework is to convert probabilities to units of avoided statistical incidences. This measure is calculated by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a measure is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature mortality amounts to $1 million ($100/0.0001 change in risk). Using this approach, the size of the affected population is automatically taken into account by the number of incidences predicted by epidemiological studies applied to the relevant population. The same type of calculation can produce values for statistical incidences of other health endpoints.

For some health effects, such as hospital admissions, WTP estimates are generally not available. In these cases, we use the cost of treating or mitigating the effect as a primary estimate. For example, for the valuation of hospital admissions we use the avoided medical costs as an estimate of the value of avoiding the health effects causing the admission. These costs of illness (COI) estimates generally understate the true value of reductions in risk of a health effect. They tend to reflect the direct expenditures related to treatment but not the value of avoided pain and suffering from the health effect. Table 9A-15 summarizes the value estimates per health effect that we used in this analysis. Values are presented both for a 1990 base income level and adjusted for income growth in the two future analysis years, 2020 and 2030. Note that the unit values for hospital admissions are the weighted averages of the ICD-9 code-specific values for the group of ICD-9 codes included in the hospital admission categories. Details of the derivation of values for hospital admissions and other endpoints can be found in the benefits TSD for this RIA (Abt Associates, 2003). A discussion of the valuation methods for premature mortality and chronic bronchitis is provided here due to the relative importance of these effects. Discussions of the methods used to value non-fatal myocardial infarctions (heart attacks) and school absence days are provided because these endpoints have not been included in previous analyses and the valuation methods are still under development. In the following discussions, unit values are presented at 1990 levels of income for consistency with previous analyses. Equivalent future year values can be obtained from Table 9A-15.

Table 9A-25. Unit Values Used for Economic Valuation of Health Endpoints (2000$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	**2020 Income Level**	**2030 Income Level**	
Premature Mortality				Base value is the mean of VSL estimates from 26 studies (5 contingent valuation and 21 labor market studies) reviewed for the Section 812 Costs and Benefits of the Clean Air Act, 1990-2010 (US EPA, 1999). Alternative VSLY estimates are derived from a VSL based on the mean of VSL estimates from the 5 contingent valuation studies referenced above. VSLY for populations under 65 are based on 35 years of assumed average remaining life expectancy. VSLY for populations 65 and older are based on 10 years of assumed average remaining life expectancy.
Base Estimate (VSL)	$6,300,000	$8,000,000	$8,100,000	
Alternative Estimate (VSLY)				
3% discount rate				
Under 65	$172,000	$217,000	$221,000	
65 and older	$434,000	$547,000	$559,000	
7% discount rate				
Under 65	$286,000	$360,000	$368,000	
65 and older	$527,000	$664,000	$678,000	
Chronic Bronchitis (CB)				Base value is the mean of a generated distribution of WTP to avoid a case of pollution-related CB. WTP to avoid a case of pollution-related CB is derived by adjusting WTP (as described in Viscusi et al., 1991) to avoid a severe case of CB for the difference in severity and taking into account the elasticity of WTP with respect to severity of CB. Alternative value is a cost of illness (COI) estimate based on Cropper and Krupnick (1990). Includes both medical costs and opportunity cost from age of onset to expected age of death (assumes that chronic bronchitis does not change life expectancy).
Base Estimate	$340,000	$430,000	$440,000	
Alternative Estimate				
3% discount rate				
Age 27-44	$150,542	$150,542	$150,542	
Age 45-64	$97,610	$97,610	$97,610	
Age 65+	$11,088	$11,088	$11,088	
7% discount rate				
Age 27-44	$86,026	$86,026	$86,026	
Age 45-64	$72,261	$72,261	$72,261	
Age 65+	$9,030	$9,030	$9,030	

Table 9A-25. Unit Values Used for Economic Valuation of Health Endpoints (2000$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	**2020 Income Level**	**2030 Income Level**	
Non-fatal Myocardial Infarction (heart attack)				Age specific cost-of-illness values reflecting lost earnings and direct medical costs over a 5 year period following a non-fatal MI. Lost earnings estimates based on Cropper and Krupnick (1990). Direct medical costs based on simple average of estimates from Russell et al. (1998) and Wittels et al. (1990). Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 yrs of lost earnings: age of onset: at 3% at 7% 25-44 $8,774 $7,855 45-54 $12,932 $11,578 55-65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al., 1990 ($102,658 – no discounting) 2. Russell et al., 1998, 5-yr period. ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
3% discount rate				
Age 0-24	$66,902	$66,902	$66,902	
Age 25-44	$74,676	$74,676	$74,676	
Age 45-54	$78,834	$78,834	$78,834	
Age 55-65	$140,649	$140,649	$140,649	
Age 66 and over	$66,902	$66,902	$66,902	
7% discount rate				
Age 0-24	$65,293	$65,293	$65,293	
Age 25-44	$73,149	$73,149	$73,149	
Age 45-54	$76,871	$76,871	$76,871	
Age 55-65	$132,214	$132,214	$132,214	
Age 66 and over	$65,293	$65,293	$65,293	
Hospital Admissions				
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total pneumonia category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Asthma admissions	$6,634	$6,634	$6,634	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).

Table 9A-25. Unit Values Used for Economic Valuation of Health Endpoints (2000$)

Health Endpoint	**Central Estimate of Value Per Statistical Incidence**			Derivation of Estimates
	1990 Income Level	**2020 Income Level**	**2030 Income Level**	
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387	The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Emergency room visits for asthma	$286	$286	$286	Simple average of two unit COI values: (1) $311.55, from Smith et al., 1997, and (2) $260.67, from Stanford et al., 1999.

Table 9A-25. Unit Values Used for Economic Valuation of Health Endpoints (2000$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	**2020 Income Level**	**2030 Income Level**	
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the 3 symptoms for which WTP estimates are available that closely match those listed by Pope, et al. result in 7 different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for URS is the average of the dollar values for the 7 different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the 4 symptoms for which WTP estimates are available that closely match those listed by Schwartz, et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS.
Acute Bronchitis	$360	$390	$390	Assumes a 6 day episode, with daily value equal to the average of low and high values for related respiratory symptoms recommended in Neumann, et al. 1994.
Restricted Activity and Work/School Loss Days				
Work Loss Days (WLDs)	Variable (national median =)			County-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5 – to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.

Table 9A-25. Unit Values Used for Economic Valuation of Health Endpoints (2000$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	**2020 Income Level**	**2030 Income Level**	
School Absence Days	$75	$75	$75	Based on expected lost wages from parent staying home with child. Estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103. The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75.
Worker Productivity	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	Based on $68 – median daily earnings of workers in farming, forestry and fishing – from Table 621, Statistical Abstract of the United States (“Full-Time Wage and Salary Workers – Number and Earnings: 1985 to 2000") (Source of data in table: U.S. Bureau of Labor Statistics, Bulletin 2307 and Employment and Earnings, monthly).
Minor Restricted Activity Days (MRADs)	$51	$55	$56	Median WTP estimate to avoid one MRAD from Tolley, et al. (1986) .

9A.3.5.5.1 Valuing Reductions in Premature Mortality Risk

Base Estimate

We estimate the monetary benefit of reducing premature mortality risk using the "value of statistical lives saved" (VSL) approach, which is a summary measure for the value of small changes in mortality risk experienced by a large number of people. The VSL approach applies information from several published value-of-life studies to determine a reasonable benefit of preventing premature mortality. The mean value of avoiding one statistical death is estimated to be $6 million in 1999 dollars. This represents an intermediate value from a variety of estimates that appear in the economics literature, and it is a value EPA has frequently used in RIAs for other rules and in the Section 812 Reports to Congress.

This estimate is the mean of a distribution fitted to the estimates from 26 value-of-life studies identified in the Section 812 reports as "applicable to policy analysis." The approach and set of selected studies mirrors that of Viscusi (1992) (with the addition of two studies), and uses the same criteria as Viscusi in his review of value-of-life studies. The $6.3 million estimate is consistent with Viscusi's conclusion (updated to 2000$) that "most of the reasonable estimates of the value of life are clustered in the $3.8 to $8.9 million range." Five of the 26 studies are contingent valuation (CV) studies, which directly solicit WTP information from subjects; the rest are wage-risk studies, which base WTP estimates on estimates of the additional compensation demanded in the labor market for riskier jobs. As indicated in the previous section on quantification of premature mortality benefits, we assume for this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the five years following exposure. To take this into account in the valuation of reductions in premature mortality, we apply an annual three percent discount rate to the value of premature mortality occurring in future years.[V]

The economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economic and public policy analysis community. Regardless of the theoretical economic considerations, EPA prefers not to draw distinctions in the monetary value assigned to the lives saved even if they differ in age, health status, socioeconomic status, gender or other characteristic of the adult population.

[V] The choice of a discount rate, and its associated conceptual basis, is a topic of ongoing discussion within the federal government. EPA adopted a 3 percent discount rate for its base estimate in this case to reflect reliance on a "social rate of time preference" discounting concept. We have also calculated benefits and costs using a 7 percent rate consistent with an "opportunity cost of capital" concept to reflect the time value of resources directed to meet regulatory requirements. In this case, the benefit and cost estimates were not significantly affected by the choice of discount rate. Further discussion of this topic appears in EPA's *Guidelines for Preparing Economic Analyses* (in press).

Following the advice of the EEAC of the SAB, EPA currently uses the VSL approach in calculating the primary estimate of mortality benefits, because we believe this calculation to provide the most reasonable single estimate of an individual's willingness to trade off money for reductions in mortality risk (EPA-SAB-EEAC-00-013). While there are several differences between the labor market studies EPA uses to derive a VSL estimate and the particulate matter air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. Table 9A-17 lists some of these differences and the expected effect on the VSL estimate for air pollution-related mortality. For example, adjusting for age differences may imply the need to adjust the $6.3 million VSL downward, but the involuntary nature of air pollution-related risks and the lower level of risk-aversion of the manual laborers in the labor market studies may imply the need for upward adjustments. In the absence of a comprehensive and balanced set of adjustment factors, EPA believes it is reasonable to continue to use the $6.3 million value while acknowledging the significant limitations and uncertainties in the available literature.

Some economists emphasize that the value of a statistical life is not a single number relevant for all situations. Indeed, the VSL estimate of $6.3 million (2000 dollars) is itself the central tendency of a number of estimates of the VSL for some rather narrowly defined populations. When there are significant differences between the population affected by a particular health risk and the populations used in the labor market studies, as is the case here, some economists prefer to adjust the VSL estimate to reflect those differences. Some of the alternative approaches that have been proposed for valuing reductions in mortality risk are discussed in Figure 9A-6.

There is general agreement that the value to an individual of a reduction in mortality risk can vary based on several factors, including the age of the individual, the type of risk, the level of control the individual has over the risk, the individual's attitudes towards risk, and the health status of the individual. While the empirical basis for adjusting the $6.3 million VSL for many of these factors does not yet exist, a thorough discussion of these factors is contained in the benefits TSD for this RIA (Abt Associates, 2003). EPA recognizes the need for investigation by the scientific community to develop additional empirical support for adjustments to VSL for the factors mentioned above.

The SAB-EEAC advised in their recent report that the EPA "continue to use a wage-risk-based VSL as its primary estimate, including appropriate sensitivity analyses to reflect the uncertainty of these estimates," and that "the only risk characteristic for which adjustments to the VSL can be made is the timing of the risk"(EPA-SAB-EEAC-00-013, U.S. EPA, 2000b). In developing our primary estimate of the benefits of premature mortality reductions, we have discounted over the lag period between exposure and premature mortality. However, in accordance with the SAB advice, we use the VSL in our primary estimate and present sensitivity estimates reflecting age-specific VSL.

Table 9A-26. Expected Impact on Estimated Benefits of Premature Mortality Reductions of Differences Between Factors Used in Developing Applied VSL and Theoretically Appropriate VSL

Attribute	**Expected Direction of Bias**
Age	Uncertain, perhaps overestimate
Life expectancy/health status	Uncertain, perhaps overestimate
Attitudes toward risk	Underestimate
Income	Uncertain
Voluntary vs. Involuntary	Uncertain, perhaps underestimate
Catastrophic vs. Protracted Death	Uncertain, perhaps underestimate

Alternative Estimate

The Alternative Estimate reflects the impact of changes to key assumptions associated with the valuation of mortality. These include: 1) the impact of using wage-risk and contingent valuation-based value of statistical life estimates in valuing risk reductions from air pollution as opposed to contingent valuation-based estimates alone, 2) the use of a value of statistical life years approach as opposed to a VSL approach, and 3) the degree of prematurity (number of life years lost) for mortalities from air pollution.

The Alternative Estimate addresses the first issue by using an estimate of the value of statistical life that is based only on the set of five contingent valuation studies included in the larger set of 26 studies recommended by Viscusi (1992) as applicable to policy analysis. The mean of the five contingent valuation based VSL estimates is $3.7 million (2000$), which is approximately 60 percent of the mean value of the full set of 26 studies. Note that because these are deaths associated with short-term exposures to $PM_{2.5}$, it is assumed that there is no lag between reduced exposure and reduced risk of mortality. Sensitivity analyses exploring the implications for the alternative estimate of using different starting VSL estimates are presented in Appendix 9B.

While the base estimate is based on a VSL approach, the alternative estimate is based on the number of years of life saved and economic value of saving a statistical life year (VSLY). The VSLY approach has been developed in the peer-reviewed economics literature (e.g., Viscusi and Moore, 1988) and has been applied for many years by the U.S. Food and Drug Administration (US FDA 1995, 1996, 1997, 1998, 1999, 2000, 2001). Some recent analyses, however, have raised concerns about the use of this method to value reductions in premature mortality in an environmental context (Science Advisory Board, 1999; Krupnick et al., 2002). The VSLY approach applied in this RIA recognizes that each year late in the life span may have a higher monetary value than the average life year saved in the middle of the life span. The non-constant VSLY, rising later in the lifespan, is qualitatively compatible with theoretical economic models of an individual's demand for lifesaving as a function of age (Shepard and Zeckhauser, 1984). The conceptional rationale for a premium on VSLY among the elderly is that they have saved through their working lifetimes and accumulated assets that can be devoted to health protection, and have rising baseline risks, which increase the marginal value of risk reductions. (Pratt and Zeckhauser 1996).

Under the alternative approach, the value of a life year for younger individuals is calculated as if they had an average life expectancy. However, instead of attempting to estimate the remaining life expectancy for different age groups, we have assumed that everyone who dies from exposure to air pollution loses five years of life. Because we assume that younger individuals do not have the accumulated assets or do not adjust the value of life years to reflect reductions in life expectancy, this approach implies that the total value of a five-year loss in life years is greater for the elderly than for younger individuals. An additional limitation of this approach is the discontinuity at age 65. A more complex approach would produce a continuous VSLY curve; however, the empirical data required to specify these models are not available.

There is no latency period assumed in the alternative analysis since the premature deaths are assumed to occur primarily among persons with chronic disease who experience short-term elevations in daily air pollution levels. Even the latency periods associated with the distributed lag models are too short to be of significance in the valuation process.

In order to implement the non-constant VSLY approach, we begin by using a VSL of of $3.7 million based on five contingent valuation studies which were also considered as part of the base estimate. This smaller VSL is also consistent with an alternative interpreation of the wage-risk literature (Mrozek and Taylor 2002). For persons under age 65, the $3.7 million VSL is assumed to reflect an average loss of 35 years. The VSLY associated with $3.7 million VSL is $172,000, annualized using a 3 percent discount rate, or $286,000, annualized using a 7 percent discount rate. Note that the larger discount rate increases the VSLY because at a higher discount rate, a larger stream of VSLY is required to yield a VSL of $3.7 million. For those over age 65, the VSLY is derived from a $3.7 million VSL and an assumed 10-year life expectancy. This gives a VSLY of $434,000 at a 3 % discount rate of a $527,000 at a 7% discount rate.

The alternative estimate also assumes that deaths from chronic obstructive pulmonary disease (COPD) are advanced by 6 months, and deaths from all other causes are advanced by 5 years. As a first approximation, these reductions in life years lost are applied regardless of the age at death. Actuarial evidence suggests that individuals with serious preexisting cardiovascular conditions have an average remaining life expectancy of around 5 years. While many deaths from daily exposure to PM may occur in individuals with cardiovascular disease, studies have shown relationships between all cause mortality and PM, and between PM and mortality from pneumonia (Schwartz, 2000). In addition, recent studies have shown a relationship between PM and non-fatal heart attacks, which suggests that some of the deaths due to PM may be due to fatal heart attacks (Peters et al., 2001). And, a recent meta-analysis has shown little effect of age on the relative risk from PM exposure (Stieb et al., 2002). The alternative estimate suggests that the number of deaths in non-elderly populations that 21 percent of non-COPD premature deaths avoided are in populations under 65 (with the possibility for greater loss of life years in this age group). Thus, while the assumption of 5 years of life lost may be appropriate for a subset of total avoided premature mortalities, it may overestimate or underestimate the degree of life shortening attributable to PM for the remaining deaths. Sensitivity analyses of the alternative estimate using different assumptions about the degree of life shortening are presented in Appendix 9B.

Monetized estimates of the benefits of a reduction in premature mortality are calculated as follows. First, the expected reduction in premature mortality by age category (over 65 and under 65) is multiplied by the assumed gain in additional discounted life years for the two disease categories (COPD and non-COPD) to obtain an estimate of the additional discounted life-years associated with the reduction in PM exposures. No adjustment is made for the quality of life-years saved. The monetized benefit estimate for a reduction in premature mortality, then, is the product of the additional discounted life-years times the calculated VSLY.

For the alternative analysis, a sensitivity analysis (Table 9B-2) was performed to reflect plausible changes in the numeric values of uncertain inputs to the mortality evaluation. The key uncertain inputs are the average number of life years lost per premature death and the starting VSL assumption. Results are presented for discount rates of 3 %.

Uncertainties Specific to Premature Mortality Valuation

The economic benefits associated with premature mortality are the largest category of monetized benefits of the Nonroad Diesel Engine rule. In addition, in prior analyses EPA has identified valuation of mortality benefits as the largest contributor to the range of uncertainty in monetized benefits (see U.S. EPA, 1999). Because of the uncertainty in estimates of the value of premature mortality avoidance, it is important to adequately characterize and understand the various types of economic approaches available for mortality valuation. Such an assessment also requires an understanding of how alternative valuation approaches reflect that some individuals may be more susceptible to air pollution-induced mortality, or reflect differences in the nature of the risk presented by air pollution relative to the risks studied in the relevant economic literature.

The health science literature on air pollution indicates that several human characteristics affect the degree to which mortality risk affects an individual. For example, some age groups appear to be more susceptible to air pollution than others (e.g., the elderly and children). Health status prior to exposure also affects susceptibility. At risk individuals include those who have suffered strokes or are suffering from cardiovascular disease and angina (Rowlatt, et al. 1998). An ideal benefits estimate of mortality risk reduction would reflect these human characteristics, in addition to an individual's willingness to pay (WTP) to improve one's own chances of survival plus WTP to improve other individuals' survival rates. The ideal measure would also take into account the specific nature of the risk reduction commodity that is provided to individuals, as well as the context in which risk is reduced. To measure this value, it is important to assess how reductions in air pollution reduce the risk of dying from the time that reductions take effect onward, and how individuals value these changes. Each individual's survival curve, or the probability of surviving beyond a given age, should shift as a result of an environmental quality improvement. For example, changing the current probability of survival for an individual also shifts future probabilities of that individual's survival. This probability shift will differ across individuals because survival curves are dependent on such characteristics as age, health state, and the current age to which the individual is likely to survive.

Although a survival curve approach provides a theoretically preferred method for valuing the benefits of reduced risk of premature mortality associated with reducing air pollution, the approach requires a great deal of data to implement. The economic valuation literature does not yet include good estimates of the value of this risk reduction commodity. As a result, in this study we value avoided premature mortality risk using the value of statistical life approach in the Base Estimate, supplemented by valuation based on the life-year method in the Alternative Estimate.

Other uncertainties specific to premature mortality valuation include the following:

- Across-study Variation: The analytical procedure used in the main analysis to estimate the monetary benefits of avoided premature mortality assumes that the appropriate economic value for each incidence is a value from the currently accepted range of the value of a statistical life. This estimate is based on 26 studies of the value of mortal risks. There is considerable uncertainty as to whether the 26 studies on the value of a statistical life provide adequate estimates of the value of a statistical life saved by air pollution reduction. Although there is considerable variation in the analytical designs and data used in the 26 underlying studies, the majority of the studies involve the value of risks to a middle-aged working population. Most of the studies examine differences in wages of risky occupations, using a wage-hedonic approach. Certain characteristics of both the population affected and the mortality risk facing that population are believed to affect the average willingness to pay (WTP) to reduce the risk. The appropriateness of a distribution of WTP estimates from the 26 studies for valuing the mortality-related benefits of reductions in air pollution concentrations therefore depends not only on the quality of the studies (i.e., how well they measure what they are trying to measure), but also on (1) the extent to which the risks being valued are similar, and (2) the extent to which the subjects in the studies are similar to the population affected by changes in pollution concentrations.

- Level of risk reduction. The transferability of estimates of the value of a statistical life from the 26 studies to the Nonroad Diesel Engine rulemaking analysis rests on the assumption that, within a reasonable range, WTP for reductions in mortality risk is linear in risk reduction. For example, suppose a study estimates that the average WTP for a reduction in mortality risk of 1/100,000 is $50, but that the actual mortality risk reduction resulting from a given pollutant reduction is 1/10,000. If WTP for reductions in mortality risk is linear in risk reduction, then a WTP of $50 for a reduction of 1/100,000 implies a WTP of $500 for a risk reduction of 1/10,000 (which is ten times the risk reduction valued in the study). Under the assumption of linearity, the estimate of the value of a statistical life does not depend on the particular amount of risk reduction being valued. This assumption has been shown to be reasonable provided the change in the risk being valued is within the range of risks evaluated in the underlying studies (Rowlatt et al. 1998).

- Voluntariness of risks evaluated. Although there may be several ways in which job-related mortality risks differ from air pollution-related mortality risks, the most important difference may be that job-related risks are incurred voluntarily, or generally assumed to be, whereas air pollution-related risks are incurred involuntarily. There is some evidence that people will pay more to reduce involuntarily incurred risks than risks incurred voluntarily. If this is the case, WTP estimates based on wage-risk studies may understate WTP to reduce involuntarily incurred air pollution-related mortality risks.

- Sudden versus protracted death. A final important difference related to the nature of the risk may be that some workplace mortality risks tend to involve sudden, catastrophic events, whereas air pollution-related risks tend to involve longer periods of disease and suffering prior to death. Some evidence suggests that WTP to avoid a risk of a protracted death involving prolonged suffering and loss of dignity and personal control is greater than the WTP to avoid a risk (of identical magnitude) of sudden death. To the extent that the mortality risks addressed in this assessment are associated with longer periods of illness or greater pain and suffering than are the risks addressed in the valuation literature, the WTP measurements employed in the present analysis would reflect a downward bias.

- Self-selection and skill in avoiding risk. Recent research (Shogren et al. 2002) suggests that VSL estimates based on hedonic wage studies may overstate the average value of a risk reduction. This is based on the fact that the risk-wage tradeoff revealed in hedonic studies reflects the preferences of the marginal worker, i.e. that worker who demands the highest compensation for his risk reduction. This worker must have either higher risk, lower risk tolerance, or both. However, the risk estimate used in hedonic studies is generally based on average risk, so the VSL may be upwardly biased because the wage differential and risk measures do not match.

9A.3.5.5.2 Valuing Reductions in the Risk of Chronic Bronchitis

Base Estimate

The best available estimate of WTP to avoid a case of chronic bronchitis (CB) comes from Viscusi, et al. (1991). The Viscusi, et al. study, however, describes a severe case of CB to the survey respondents. We therefore employ an estimate of WTP to avoid a pollution-related case of CB, based on adjusting the Viscusi, et al. (1991) estimate of the WTP to avoid a severe case. This is done to account for the likelihood that an average case of pollution-related CB is not as severe. The adjustment is made by applying the elasticity of WTP with respect to severity reported in the Krupnick and Cropper (1992) study. Details of this adjustment procedure are provided in the benefits TSD for this RIA (Abt Associates, 2003).

We use the mean of a distribution of WTP estimates as the central tendency estimate of WTP to avoid a pollution-related case of CB in this analysis. The distribution incorporates uncertainty from three sources: (1) the WTP to avoid a case of severe CB, as described by Viscusi, et al.; (2) the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi, et al.); and (3) the elasticity of WTP with respect to severity of the illness. Based on assumptions about the distributions of each of these three uncertain components, we derive a distribution of WTP to avoid a pollution-related case of CB by statistical uncertainty analysis techniques. The expected value (i.e., mean) of this distribution, which is about $331,000 (2000$), is taken as the central tendency estimate of WTP to avoid a PM-related case of CB.

Alternative Estimate

For the Alternative Estimate, a cost-of illness value is used in place of willingness-to-pay to reflect uncertainty about the value of reductions in incidences of chronic bronchitis. In the Base Estimate, the willingness-to-pay estimate was derived from two contingent valuation studies (Viscusi et al., 1991; Krupnick and Cropper, 1992). These studies were experimental studies intended to examine new methodologies for eliciting values for morbidity endpoints. Although these studies were not specifically designed for policy analysis, the SAB (EPA-SAB-COUNCIL-ADV-00-002, 1999) has indicated that the severity-adjusted values from this study provide reasonable estimates of the WTP for avoidance of chronic bronchitis. As with other contingent valuation studies, the reliability of the WTP estimates depends on the methods used to obtain the WTP values. In order to investigate the impact of using the CV based WTP estimates, the Alternative Estimate relies on estimates of lost earnings and medical costs. Using age-specific annual lost earnings and medical costs estimated by Cropper and Krupnick (1990) and a three percent discount rate, we estimated a lifetime present discounted value (in 2000$) due to chronic bronchitis of $150,542 for someone between the ages of 27 and 44; $97,610 for someone between the ages of 45 and 64; and $11,088 for someone over 65. The corresponding age-specific estimates of lifetime present discounted value (in 2000$) using a seven percent discount rate are $86,026, $72,261, and assuming $9,030, respectively. These estimates assumed that 1) lost earnings continue only until age 65, 2) medical expenditures are incurred until death, and 3) life expectancy is unchanged by chronic bronchitis.

9A.3.5.5.3 Valuing Reductions in Non-Fatal Myocardial Infarctions (Heart Attacks)

The Agency has not previously estimated the impact of its programs on reductions in the expected number of non-fatal heart attacks, although it has examined the impact of reductions in other related cardiovascular endpoints[w]. We were not able to identify a suitable WTP value for reductions in the risk of non-fatal heart attacks. Instead, we propose a cost-of-illness unit value with two components: the direct medical costs and the opportunity cost (lost earnings) associated with the illness event. Because the costs associated with an MI extend beyond the initial event itself, we consider costs incurred over several years. Using age-specific annual lost earnings estimated by Cropper and Krupnick (1990), and a three percent discount rate, we estimated a present discounted value in lost earnings (in 2000$) over 5 years due to an MI of $8,774 for someone between the ages of 25 and 44, $12,932 for someone between the ages of 45 and 54, and $74,746 for someone between the ages of 55 and 65. The corresponding age-specific estimates of lost earnings (in 2000$) using a seven percent discount rate are $7,855, $11,578, and $66,920, respectively. Cropper and Krupnick (1990) do not provide lost earnings estimates for

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[w]

populations under 25 or over 65. As such we do not include lost earnings in the cost estimates for these age groups.

We have found three possible sources in the literature of estimates of the direct medical costs of MI:

- Wittels et al. (1990) estimated expected total medical costs of MI over 5 years to be $51,211 (in 1986$) for people who were admitted to the hospital and survived hospitalization. (There does not appear to be any discounting used.) Wittels et al. was used to value coronary heart disease in the 812 Retrospective Analysis of the Clean Air Act. Using the CPI-U for medical care, the Wittels estimate is $109,474 in year 2000$. This estimated cost is based on a medical cost model, which incorporated therapeutic options, projected outcomes and prices (using "knowledgeable cardiologists" as consultants). The model used medical data and medical decision algorithms to estimate the probabilities of certain events and/or medical procedures being used. The authors note that the average length of hospitalization for acute MI has decreased over time (from an average of 12.9 days in 1980 to an average of 11 days in 1983). Wittels et al. used 10 days as the average in their study. It is unclear how much further the length of stay (LOS) for MI may have decreased from 1983 to the present. The average LOS for ICD code 410 (MI) in the year-2000 AHQR HCUP database is 5.5 days. However, this may include patients who died in the hospital (not included among our non-fatal MI cases), whose LOS was therefore substantially shorter than it would be if they hadn't died.

- Eisenstein et al. (2001) estimated 10-year costs of $44,663, in 1997$, or $49,651 in 2000$ for MI patients, using statistical prediction (regression) models to estimate inpatient costs. Only inpatient costs (physician fees and hospital costs) were included.

- Russell et al. (1998) estimated first-year direct medical costs of treating nonfatal MI of $15,540 (in 1995$), and $1,051 annually thereafter. Converting to year 2000$, that would be $23,353 for a 5-year period (without discounting), or $29,568 for a ten-year period.

In summary, the three different studies provided significantly different values:

Table 9A-27.
Alternative Direct Medical Cost of Illness Estimates for Nonfatal Heart Attacks

Study	Direct Medical Costs (2000$)	Over an x-year period, for x =
Wittels et al., 1990	$109,474*	5
Russell et al., 1998	$22,331**	5
Eisenstein et al., 2001	$49,651**	10
Russell et al., 1998	$27,242**	10

*Wittels et al. did not appear to discount costs incurred in future years.

**Using a 3 percent discount rate.

As noted above, the estimates from these three studies are substantially different, and we have not adequately resolved the sources of differences in the estimates. Because the wage-related opportunity cost estimates from Cropper and Krupnick, 1990, cover a 5-year period, we will use estimates for medical costs that similarly cover a 5-year period – i.e., estimates from Wittels et al., 1990, and Russell et al., 1998. We will use a simple average of the two 5-year estimates, or $65,902, and add it to the 5-year opportunity cost estimate. The resulting estimates are given in the table below.

Table 9A-28.
Estimated Costs Over a 5-Year Period (in 2000$) of a Non-Fatal Myocardial Infarction

Age Group	Opportunity Cost	Medical Cost**	Total Cost
0 - 24	$0	$65,902	$65,902
25-44	$8,774*	$65,902	$74,676
45 - 54	$12,253*	$65,902	$78,834
55 - 65	$70,619*	$65,902	$140,649
> 65	$0	$65,902	$65,902

*From Cropper and Krupnick, 1990, using a 3% discount rate.

**An average of the 5-year costs estimated by Wittels et al., 1990, and Russell et al., 1998.

9A.3.5.5.4 Valuing Reductions in School Absence Days

School absences associated with exposure to ozone are likely to be due to respiratory-related symptoms and illnesses. Because the respiratory symptom and illness endpoints we are including are all PM-related rather than ozone-related, we do not have to be concerned about double counting of benefits if we aggregate the benefits of avoiding ozone-related school absences with the benefits of avoiding PM-related respiratory symptoms and illnesses.

One possible approach to valuing a school absence is using a parental opportunity cost approach. This method requires two steps: (1) estimate the probability that, if a school child stays home from school, a parent will have to stay home from work to care for the child, and (2) value the lost productivity at the person's wage. Using this method, we would estimate the proportion of families with school-age children in which both parents work, and value a school loss day as the probability of a work loss day resulting from a school loss day (i.e., the proportion of households with school-age children in which both parents work) times some measure of lost wages (whatever measure we use to value work loss days). There are two significant problems with this method, however. First, it omits WTP to avoid the symptoms/illness which resulted in the school absence. Second, it effectively gives zero value to school absences which do not result in a work loss day (unless we derive an alternative estimate of the value of the parent's time for those cases in which the parent is not in the labor force). We are investigating approaches using WTP for avoid the symptoms/illnesses causing the absence. In the interim, we will use the parental opportunity cost approach.

For the parental opportunity cost approach, we make an explicit, conservative assumption that in married households with two working parents, the female parent will stay home with a sick child. From the U.S. Census Bureau, Statistical Abstract of the United States: 2001, we obtained (1) the numbers of single, married, and "other" (i.e., widowed, divorced, or separated) women with children in the workforce, and (2) the rates of participation in the workforce of single, married, and "other" women with children. From these two sets of statistics, we inferred the numbers of single, married, and "other" women with children, and the corresponding percentages. These percentages were used to calculate a weighted average participation rate, as shown in the table below.

Table 9A-29.
Women with Children: Number and Percent in the Labor Force, 2000, and Weighted Average Participation Rate*

	Number (in millions) in Labor Force (1)	Participation Rate (2)	Implied Total Number in Population (in millions) (3) = (1)/(2)	Implied Percent in Population (4)	Weighted Average Participation Rate [=sum (2)*(4) over rows]
Single	3.1	73.9%	4.19	11.84%	
Married	18.2	70.6%	25.78	72.79%	
Other**	4.5	82.7%	5.44	15.36%	
Total:			35.42		
					72.85%

*Data in columns (1) and (2) are from U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 577.
**Widowed, divorced, or separated.

Our estimated daily lost wage (if a mother must stay at home with a sick child) is based on the median weekly wage among women age 25 and older in 2000 (U.S. Census Bureau, Statistical Abstract of the United States: 2001, Section 12: Labor Force, Employment, and Earnings, Table No. 621). This median wage is $551. Dividing by 5 gives an estimated median daily wage of $103.

The expected loss in wages due to a day of school absence in which the mother would have to stay home with her child is estimated as the probability that the mother is in the workforce times the daily wage she would lose if she missed a day = 72.85% of $103, or $75.

9A.3.5.6 Unquantified Health Effects

In addition to the health effects discussed above, there is emerging evidence that human exposure to ozone may be associated with premature mortality (Ito and Thurston, 1996; Samet, et al. 1997, Ito and Thurston, 2001), PM with infant mortality (Woodruff, et al., 1997) and cancer (US EPA, 1996b), PM and ozone with increased emergency room visits for non-asthma respiratory causes (US EPA, 1996a; 1996b), ozone with impaired airway responsiveness (US EPA, 1996a), ozone with increased susceptibility to respiratory infection (US EPA, 1996a), ozone with acute inflammation and respiratory cell damage (US EPA, 1996a), ozone and PM with premature aging of the lungs and chronic respiratory damage (US EPA, 1996a; 1996b), and PM with reduced heart rate variability and other changes in cardiac function. An improvement in ambient PM and ozone air quality may reduce the number of incidences within each effect category that the U.S. population would experience. Although these health effects are believed to be PM or ozone-induced, C-R data are not available for quantifying the benefits associated with reducing these effects. The inability to quantify these effects lends a downward bias to the monetized benefits presented in this analysis.

Another category of potential effects that may change in response to ozone reduction strategies results from the shielding provided by ozone against the harmful effects of ultraviolet radiation (UV-B) derived from the sun. The great majority of this shielding results from naturally occurring ozone in the stratosphere, but the 10 percent of total “column”ozone present in the troposphere also contributes (NAS, 1991). A variable portion of this tropospheric fraction of UV-B shielding is derived from ground level or “smog” ozone related to anthropogenic air pollution. Therefore, strategies that reduce ground level ozone could, in some small measure, increase exposure to UV-B from the sun.

While it is possible to provide quantitative estimates of benefits associated with globally based strategies to restore the far larger and more spatially uniform stratospheric ozone layer, the changes in UV-B exposures associated with ground level ozone reduction strategies are much more complicated and uncertain. Smog ozone strategies, such as mobile source controls, are focused on decreasing peak ground level ozone concentrations, and it is reasonable to conclude that they produce a far more complex and heterogeneous spatial and temporal pattern of ozone concentration and UV-B exposure changes than do stratospheric ozone protection programs. In addition, the changes in long-term total column ozone concentrations are far smaller from ground-level programs. To properly estimate the change in exposure and impacts, it would be necessary to match the spatial and temporal distribution of the changes in ground-level ozone to the spatial and temporal distribution of exposure to ground level ozone and sunlight. More importantly, it is long-term exposure to UV-B that is associated with effects. Intermittent, short-term, and relatively small changes in ground-level ozone and UV-B are not likely to measurably change long-term risks of these adverse effects.

For all of these reasons, we were unable to provide reliable estimates of the changes in UV-B shielding associated with ground-level ozone changes. This inability lends an upward bias to the net monetized benefits presented in this analysis. It is likely that the adverse health effects associated with increases in UV-B exposure from decreased tropospheric ozone would, however, be relatively very small from a public health perspective because 1) the expected long-term ozone change resulting from this rule is small relative to total anthropogenic tropospheric ozone, which in turn is small in comparison to total column natural stratospheric and tropospheric ozone; 2) air quality management strategies are focused on decreasing peak ozone concentrations and thus may change exposures over limited areas for limited times; 3) people often receive peak exposures to UV-B in coastal areas where sea or lake breezes reduce ground level pollution concentrations regardless of strategy; and 4) ozone concentration changes are greatest in urban areas and areas immediately downwind of urban areas. In these areas, people are more likely to spend most of their time indoors or in the shade of buildings, trees or vehicles.

9A.3.6 Human Welfare Impact Assessment

PM and ozone have numerous documented effects on environmental quality that affect human welfare. These welfare effects include direct damages to property, either through impacts on material structures or by soiling of surfaces, direct economic damages in the form of lost productivity of crops and trees, indirect damages through alteration of ecosystem functions, and indirect economic damages through the loss in value of recreational experiences or the existence value of important resources. EPA's Criteria Documents for PM and ozone list numerous physical and ecological effects known to be linked to ambient concentrations of these pollutants (US EPA, 1996a; 1996b). This section describes individual effects and how we quantify and monetize them. These effects include changes in commercial crop and forest yields, visibility, and nitrogen deposition to estuaries.

9A.3.6.1 Visibility Benefits

Changes in the level of ambient particulate matter caused by the reduction in emissions from the preliminary control options will change the level of visibility in much of the U.S. Visibility directly affects people's enjoyment of a variety of daily activities. Individuals value visibility both in the places they live and work, in the places they travel to for recreational purposes, and at sites of unique public value, such as the Grand Canyon. This section discusses the measurement of the economic benefits of visibility.

It is difficult to quantitatively define a visibility endpoint that can be used for valuation. Increases in PM concentrations cause increases in light extinction. Light extinction is a measure of how much the components of the atmosphere absorb light. More light absorption means that the clarity of visual images and visual range is reduced, *ceteris paribus.* Light absorption is a variable that can be accurately measured. Sisler (1996) created a unitless measure of visibility based directly on the degree of measured light absorption called the *deciview*. Deciviews are standardized for a reference distance in such a way that one deciview corresponds to a change of about 10 percent in available light. Sisler characterized a change in light extinction of one deciview as "a small but perceptible scenic change under many circumstances." Air quality models were used to predict the change in visibility, measured in deciviews, of the areas affected by the preliminary control options.[x]

EPA considers benefits from two categories of visibility changes: residential visibility and recreational visibility. In both cases economic benefits are believed to consist of both use values and non-use values. Use values include the aesthetic benefits of better visibility, improved road

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[x] A change of less than 10 percent in the light extinction budget represents a measurable improvement in visibility, but may not be perceptible to the eye in many cases. Some of the average regional changes in visibility are less than one deciview (i.e. less than 10 percent of the light extinction budget), and thus less than perceptible. However, this does not mean that these changes are not real or significant. Our assumption is then that individuals can place values on changes in visibility that may not be perceptible. This is quite plausible if individuals are aware that many regulations lead to small improvements in visibility which when considered together amount to perceptible changes in visibility.

and air safety, and enhanced recreation in activities like hunting and birdwatching. Non-use values are based on people's beliefs that the environment ought to exist free of human-induced haze. Non-use values may be a more important component of value for recreational areas, particularly national parks and monuments.

Residential visibility benefits are those that occur from visibility changes in urban, suburban, and rural areas, and also in recreational areas not listed as federal Class I areas.[y] For the purposes of this analysis, recreational visibility improvements are defined as those that occur specifically in federal Class I areas. A key distinction between recreational and residential benefits is that only those people living in residential areas are assumed to receive benefits from residential visibility, while all households in the U.S. are assumed to derive some benefit from improvements in Class I areas. Values are assumed to be higher if the Class I area is located close to their home.[z]

Only two existing studies provide defensible monetary estimates of the value of visibility changes. One is a study on residential visibility conducted in 1990 (McClelland, et. al., 1993) and the other is a 1988 survey on recreational visibility value (Chestnut and Rowe, 1990a; 1990b). Both utilize the contingent valuation method. There has been a great deal of controversy and significant development of both theoretical and empirical knowledge about how to conduct CV surveys in the past decade. In EPA's judgment, the Chestnut and Rowe study contains many of the elements of a valid CV study and is sufficiently reliable to serve as the basis for monetary estimates of the benefits of visibility changes in recreational areas.[aa] This study serves as an essential input to our estimates of the benefits of recreational visibility improvements in the primary benefits estimates. Consistent with SAB advice, EPA has designated the McClelland, et al. study as significantly less reliable for regulatory benefit-cost analysis, although it does provide useful estimates on the order of magnitude of residential visibility benefits (EPA-SAB-COUNCIL-ADV-00-002, 1999). Residential visibility benefits are therefore only included as a sensitivity estimate in Appendix 9-B.

The Chestnut and Rowe study measured the demand for visibility in Class I areas managed by the National Park Service (NPS) in three broad regions of the country: California, the Southwest, and the Southeast. Respondents in five states were asked about their willingness to pay to protect national parks or NPS-managed wilderness areas within a particular region. The survey used photographs reflecting different visibility levels in the specified recreational areas. The visibility levels in these photographs were later converted to deciviews for the current

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[Y] The Clean Air Act designates 156 national parks and wilderness areas as Class I areas for visibility protection.

[Z] For details of the visibility estimates discussed in this chapter, please refer to the benefits technical support document for this RIA (Abt Associates 2003).

[AA] An SAB advisory letter indicates that"many members of the Council believe that the Chestnut and Rowe study is the best available." (EPA-SAB-COUNCIL-ADV-00-002, 1999) However, the committee did not formally approve use of these estimates because of concerns about the peer-reviewed status of the study. EPA believes the study has received adequate review and has been cited in numerous peer-reviewed publications (Chestnut and Dennis, 1997).

analysis. The survey data collected were used to estimate a WTP equation for improved visibility. In addition to the visibility change variable, the estimating equation also included household income as an explanatory variable.

The Chestnut and Rowe study did not measure values for visibility improvement in Class I areas outside the three regions. Their study covered 86 of the 156 Class I areas in the U.S. We can infer the value of visibility changes in the other Class I areas by transferring values of visibility changes at Class I areas in the study regions. However, these values are not as defensible and are thus presented only as an alternative calculation in Table 9A-25. A complete description of the benefits transfer method used to infer values for visibility changes in Class I areas outside the study regions is provided in the benefits TSD for this RIA (Abt Associates, 2003).

The estimated relationship from the Chestnut and Rowe study is only directly applicable to the populations represented by survey respondents. EPA used benefits transfer methodology to extrapolate these results to the population affected by the Nonroad Diesel Engines rule. A general willingness to pay equation for improved visibility (measured in deciviews) was developed as a function of the baseline level of visibility, the magnitude of the visibility improvement, and household income. The behavioral parameters of this equation were taken from analysis of the Chestnut and Rowe data. These parameters were used to calibrate WTP for the visibility changes resulting from the Nonroad Diesel Engines rule. The method for developing calibrated WTP functions is based on the approach developed by Smith, et al. (2002). Available evidence indicates that households are willing to pay more for a given visibility improvement as their income increases (Chestnut, 1997). The benefits estimates here incorporate Chestnut's estimate that a 1 percent increase in income is associated with a 0.9 percent increase in WTP for a given change in visibility.

Using the methodology outlined above, EPA estimates that the total WTP for the visibility improvements in California, Southwestern, and Southeastern Class I areas brought about by the Nonroad Diesel Engines rule is $2.2 billion. This value includes the value to households living in the same state as the Class I area as well as values for all households in the U.S. living outside the state containing the Class I area, and the value accounts for growth in real income. We examine the impact of expanding the visibility benefits analysis to other areas of the country in a sensitivity analysis presented in Appendix 9-B.

One major source of uncertainty for the visibility benefit estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for willingness to pay for the affected population could have significant effects on the size of the estimates. Assumptions about how individuals respond to changes in visibility that are either very small, or outside the range covered in the Chestnut and Rowe study, could also affect the results.

9A.3.6.2 Agricultural, Forestry and other Vegetation Related Benefits

The Ozone Criteria Document notes that “ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant” (US EPA, 1996). Changes in ground level ozone resulting from the preliminary control options are expected to impact crop and forest yields throughout the affected area.

Well-developed techniques exist to provide monetary estimates of these benefits to agricultural producers and to consumers. These techniques use models of planting decisions, yield response functions, and agricultural products supply and demand. The resulting welfare measures are based on predicted changes in market prices and production costs. Models also exist to measure benefits to silvicultural producers and consumers. However, these models have not been adapted for use in analyzing ozone related forest impacts. As such, our analysis provides monetized estimates of agricultural benefits, and a discussion of the impact of ozone changes on forest productivity, but does not monetize commercial forest related benefits.

9A.3.6.2.1 Agricultural Benefits

Laboratory and field experiments have shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that “several economically important crop species are sensitive to ozone levels typical of those found in the U.S.” (US EPA, 1996). In addition, economic studies have shown a relationship between observed ozone levels and crop yields (Garcia, et al., 1986). The economic value associated with varying levels of yield loss for ozone-sensitive commodity crops is analyzed using the AGSIM© agricultural benefits model (Taylor, et al., 1993). AGSIM© is an econometric-simulation model that is based on a large set of statistically estimated demand and supply equations for agricultural commodities produced in the United States. The model is capable of analyzing the effects of changes in policies (in this case, the implementation of the Nonroad Diesel Engines rule) that affect commodity crop yields or production costs.[bb]

The measure of benefits calculated by the model is the net change in consumer and producer surplus from baseline ozone concentrations to the ozone concentrations resulting from attainment of particular standards. Using the baseline and post-control equilibria, the model calculates the change in net consumer and producer surplus on a crop-by-crop basis.[cc] Dollar

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[BB] AGSIM© is designed to forecast agricultural supply and demand out to 2010. We were not able to adapt the model to forecast out to 2030. Instead, we apply percentage increases in yields from decreased ambient ozone levels in 2030 to 2010 yield levels, and input these into an agricultural sector model held at 2010 levels of demand and supply. It is uncertain what impact this assumption will have on net changes in surplus.

[CC] Agricultural benefits differ from other health and welfare endpoints in the length of the assumed ozone season. For agriculture, the ozone season is assumed to extend from April to September. This assumption is made to ensure proper calculation of the ozone statistic used in the exposure-response functions. The only crop affected by changes in ozone during April is winter wheat.

values are aggregated across crops for each standard. The total dollar value represents a measure of the change in social welfare associated with the Nonroad Diesel Engines rule.

The model employs biological exposure-response information derived from controlled experiments conducted by the NCLAN (NCLAN, 1996). For the purpose of our analysis, we analyze changes for the six most economically significant crops for which C-R functions are available: corn, cotton, peanuts, sorghum, soybean, and winter wheat.[dd] For some crops there are multiple C-R functions, some more sensitive to ozone and some less. Our base estimate assumes that crops are evenly mixed between relatively sensitive and relatively insensitive varieties. Sensitivity to this assumption is tested in Appendix 9-B.

9A.3.6.2.2 Forestry Benefits

Ozone also has been shown conclusively to cause discernible injury to forest trees (US EPA, 1996; Fox and Mickler, 1996). In our previous analysis of the HD Engine/Diesel Fuel rule, we were able to quantify the effects of changes in ozone concentrations on tree growth for a limited set of species. Due to data limitations, we were not able to quantify such impacts for this analysis. We plan to assess both physical impacts on tree growth and the economic value of those phyisical impacts in our analysis of the final rule. We will use econometric models of forest product supply and demand to estimate changes in prices, producer profits and consumer surplus.

9A.3.6.2.3 Other Vegetation Effects

An additional welfare benefit expected to accrue as a result of reductions in ambient ozone concentrations in the U.S. is the economic value the public receives from reduced aesthetic injury to forests. There is sufficient scientific information available to reliably establish that ambient ozone levels cause visible injury to foliage and impair the growth of some sensitive plant species (US EPA, 1996c, p. 5-521). However, present analytic tools and resources preclude EPA from quantifying the benefits of improved forest aesthetics.

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels and likely to impact large economic sectors. In the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative economic benefits analysis has been conducted. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals (Abt Associates, 1995), both by private property owners/tenants and by governmental units responsible for public areas. This is therefore a potentially important welfare effects category. However, information and valuation methods are not available to allow for plausible estimates of the percentage of these expenditures that may be related to impacts associated with ozone exposure.

[DD] The total value for these crops in 1998 was $47 billion.

The nonroad diesel standards, by reducing NO_X emissions, will also reduce nitrogen deposition on agricultural land and forests. There is some evidence that nitrogen deposition may have positive effects on agricultural output through passive fertilization. Holding all other factors constant, farmers' use of purchased fertilizers or manure may increase as deposited nitrogen is reduced. Estimates of the potential value of this possible increase in the use of purchased fertilizers are not available, but it is likely that the overall value is very small relative to other health and welfare effects. The share of nitrogen requirements provided by this deposition is small, and the marginal cost of providing this nitrogen from alternative sources is quite low. In some areas, agricultural lands suffer from nitrogen over-saturation due to an abundance of on-farm nitrogen production, primarily from animal manure. In these areas, reductions in atmospheric deposition of nitrogen from PM represent additional agricultural benefits.

Information on the effects of changes in passive nitrogen deposition on forests and other terrestrial ecosystems is very limited. The multiplicity of factors affecting forests, including other potential stressors such as ozone, and limiting factors such as moisture and other nutrients, confound assessments of marginal changes in any one stressor or nutrient in forest ecosystems. However, reductions in deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (US EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (US EPA, 1993). Once saturation is reached, adverse effects of additional nitrogen begin to occur such as soil acidification which can lead to leaching of nutrients needed for plant growth and mobilization of harmful elements such as aluminum. Increased soil acidification is also linked to higher amounts of acidic runoff to streams and lakes and leaching of harmful elements into aquatic ecosystems.

9A.3.6.3 Benefits from Reductions in Materials Damage

The preliminary control options that we modeled are expected to produce economic benefits in the form of reduced materials damage. There are two important categories of these benefits. Household soiling refers to the accumulation of dirt, dust, and ash on exposed surfaces. Criteria pollutants also have corrosive effects on commercial/industrial buildings and structures of cultural and historical significance. The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

Previous EPA benefit analyses have been able to provide quantitative estimates of household soiling damage. Consistent with SAB advice, we determined that the existing data (based on consumer expenditures from the early 1970's) are too out of date to provide a reliable enough estimate of current household soiling damages (EPA-SAB-Council-ADV-003, 1998) to include in our base estimate. We calculate household soiling damages in a sensitivity estimate provided in Appendix 9B.

EPA is unable to estimate any benefits to commercial and industrial entities from reduced materials damage. Nor is EPA able to estimate the benefits of reductions in PM-related damage to historic buildings and outdoor works of art. Existing studies of damage to this latter category in Sweden (Grosclaude and Soguel, 1994) indicate that these benefits could be an order of magnitude larger than household soiling benefits.

9A.3.6.4 Benefits from Reduced Ecosystem Damage

The effects of air pollution on the health and stability of ecosystems are potentially very important, but are at present poorly understood and difficult to measure. The reductions in NO_X caused by the final rule could produce significant benefits. Excess nutrient loads, especially of nitrogen, cause a variety of adverse consequences to the health of estuarine and coastal waters. These effects include toxic and/or noxious algal blooms such as brown and red tides, low (hypoxic) or zero (anoxic) concentrations of dissolved oxygen in bottom waters, the loss of submerged aquatic vegetation due to the light-filtering effect of thick algal mats, and fundamental shifts in phytoplankton community structure (Bricker et al., 1999).

Direct C-R functions relating changes in nitrogen loadings to changes in estuarine benefits are not available. The preferred WTP based measure of benefits depends on the availability of these C-R functions and on estimates of the value of environmental responses. Because neither appropriate C-R functions nor sufficient information to estimate the marginal value of changes in water quality exist at present, calculation of a WTP measure is not possible.

If better models of ecological effects can be defined, EPA believes that progress can be made in estimating WTP measures for ecosystem functions. These estimates would be superior to avoided cost estimates in placing economic values on the welfare changes associated with air pollution damage to ecosystem health. For example, if nitrogen or sulfate loadings can be linked to measurable and definable changes in fish populations or definable indexes of biodiversity, then CV studies can be designed to elicit individuals' WTP for changes in these effects. This is an important area for further research and analysis, and will require close collaboration among air quality modelers, natural scientists, and economists.

9A.4 Benefits Analysis—Results

Applying the C-R and valuation functions described in Section C to the estimated changes in ozone and PM described in Section B yields estimates of the changes in physical damages (i.e. premature mortalities, cases, admissions, change in deciviews, increased crop yields, etc.) and the associated monetary values for those changes. Estimates of physical health impacts are presented in Table 9A.9. Monetized values for both health and welfare endpoints are presented in Table 9A.10, along with total aggregate monetized benefits. All of the monetary benefits are in constant year 2000 dollars.

Not all known PM- and ozone-related health and welfare effects could be quantified or monetized. The monetized value of these unquantified effects is represented by adding an unknown "B" to the aggregate total. The estimate of total monetized health benefits is thus equal to the subset of monetized PM- and ozone-related health and welfare benefits plus B, the sum of the unmonetized health and welfare benefits.

Both the Base and Alternative estimates are dominated by benefits of mortality risk reductions. The Base estimate projects that the modeled preliminary control options will result in 6,200 avoided premature deaths in 2020 and 11,000 avoided premature deaths in 2030. The Alternative estimate projects that reductions in short-term $PM_{2.5}$ exposures alone will result in 3,700 avoided premature deaths in 2020 and 6,600 avoided premature deaths in 2030. The increase in benefits from 2020 to 2030 reflects additional emission reductions from the standards, as well as increases in total population and the average age (and thus baseline mortality risk) of the population. The omission of possible long-term impacts of particulate matter on mortality accounts for an approximately 40 percent reduction in the estimate of avoided premature mortality in the Alternative Estimate relative to the Base Estimate.

Our Base estimate of total monetized benefits in 2030 for the modeled nonroad preliminary control options is $92 billion using a 3 percent discount rate and $87 billion using a 7 percent discount rate. In 2020, the base monetized benefits are estimated at $52 billion using a 3 percent discount rate and $47 billion using a 7 percent discount rate. Health benefits account for 94 percent of total benefits. The monetized benefit associated with reductions in the risk of premature mortality, which accounts for $85 billion in 2030 and $47 billion in 2020, is over 90 percent of total monetized health benefits. The next largest benefit is for reductions in chronic illness (chronic bronchitis and non-fatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Visibility, minor restricted activity days, work loss days, school absence days, and worker productivity account for the majority of the remaining benefits. The remaining categories account for less than $10 million each, however, they represent a large number of avoided incidences affecting many individuals.

The alternative estimate of total monetized benefits in 2030 for the modeled preliminary control option is $19 billion using a 3 percent discount rate and $20 billion using a 7 percent discount rate. In 2020, the alternative monetized benefits are estimated at $11 billion using a 3 percent discount rate and $11 billion using a 7 percent discount rate. Health benefits account for around 80 percent of the total alternative benefits estimates. The 40 percent reduction in mortality under the Alternative Estimate and the difference in valuation of premature mortality and chronic bronchitis explain the difference in benefits between these two approaches.

A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are 100 times more work loss days than premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of WTP. As such the true value of these effects may be higher than that reported in Table 9A.9.

Ozone benefits are in aggregate positive for the nation. However, due to ozone increases occurring during certain hours of the day in some urban areas, in 2020 the net effect is an increase in minor restricted activity days, which are related to changes in daily average ozone (which includes hours during which ozone levels are low, but are increased relative to the baseline). However, by 2030, there is a net decrease in MRAD consistent with widespread reductions in ozone concentrations from the increased NOX emissions reductions. Overall, ozone benefits are low relative to PM benefits for similar endpoint categories because of the increases in ozone concentrations during some hours of some days in certain urban areas. For a more complete discussion of this issue, see Chapter 3.

Table 9A.30.
Reductions in Incidence of Adverse Health Effects Associated with Reductions in Particulate Matter and Ozone Associated with the Modeled Preliminary Control Option

Endpoint	Avoided Incidence[A] (cases/year)	
	2020	2030
PM-related Endpoints		
Premature mortality[B] -		
Base estimate: Long-term exposure (adults, 30 and over)	6,200	11,000
Alternative estimate: Short-term exposure (all ages)	3,700	6,600
Chronic bronchitis (adults, 26 and over)	4,300	6,500
Non-fatal myocardial infarctions (adults, 18 and older)	11,000	18,000
Hospital admissions – Respiratory (all ages)[C]	3,100	5,500
Hospital admissions – Cardiovascular (adults, 20 and older)[D]	3,300	5,700
Emergency Room Visits for Asthma (18 and younger)	4,300	6,500
Acute bronchitis (children, 8-12)	10,000	16,000
Lower respiratory symptoms (children, 7-14)	110,000	170,000
Upper respiratory symptoms (asthmatic children, 9-11)	92,000	120,000
Work loss days (adults, 18-65)	780,000	1,100,000
Minor restricted activity days (adults, age 18-65)	4,600,000	6,500,000
Ozone-related Endpoints		
Hospital Admissions – Respiratory Causes (adults, 65 and older)[E]	370	1,100
Hospital Admissions - Respiratory Causes (children, under 2 years)	150	280
Emergency Room Visits for Asthma (all ages)	93	200
Minor restricted activity days (adults, age 18-65)	(2,400)	96,000
School absence days (children, age 6-11)	65,000	96,000

[A] Incidences are rounded to two significant digits.
[B] Premature mortality associated with ozone is not separately included in this analysis
[C] Respiratory hospital admissions for PM includes admissions for COPD, pneumonia, and asthma.
[D] Cardiovascular hospital admissions for PM includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.
[E] Respiratory hospital admissions for ozone includes admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 9A.31
Results of Human Health and Welfare Benefits Valuation for the Modeled Preliminary Nonroad Diesel Engine Standards

Endpoint	Pollutant	Monetary Benefits[A,B] (millions 2000$, Adjusted for Income Growth)	
		2020	2030
Premature mortality[C]	PM		
Base estimate: Long-term exposure, (adults, 30 and over)			
3% discount rate		$47,000	$85,000
7% discount rate		$44,000	$80,000
Alternative estimate: Short-term exposure, (all ages)			
3% discount rate		$7,200	$13,000
7% discount rate		$8,200	$15,000
Chronic bronchitis (adults, 26 and over)	PM		
Base estimate: Willingness-to-pay		$1,900	$3,000
Alternative estimate: Cost-of-illness			
3% discount rate		$420	$600
7% discount rate		$270	$390
Non-fatal myocardial infarctions	PM		
3% discount rate		$900	$1,400
7% discount rate		$870	$1,400
Hospital Admissions from Respiratory Causes	O_3 and PM	$55	$110
Hospital Admissions from Cardiovascular Causes	PM	$72	$120
Emergency Room Visits for Asthma	O_3 and PM	$1	$2
Acute bronchitis (children, 8-12)	PM	$4	$6
Lower respiratory symptoms (children, 7-14)	PM	$2	$3
Upper respiratory symptoms (asthmatic children, 9-11)	PM	$2	$3
Work loss days (adults, 18-65)	PM	$110	$150
Minor restricted activity days (adults, age 18-65)	O_3 and PM	$250	$370
School absence days (children, age 6-11)	O_3	$5	$10
Worker productivity (outdoor workers, age 18-65)	O_3	$4	$7
Recreational visibility (86 Class I Areas)	PM	$1,400	$2,200
Agricultural crop damage (6 crops)	O_3	$89	$140
Monetized Total[H]	O_3 and PM		
Base estimate			
3% discount rate		$52,000+B	$92,000+B
7% discount rate		$49,000+B	$87,000+B
Alternative estimate			
3% discount rate		$11,000+B	$19,000+B
7% discount rate		$11,000+B	$20,000+B

[A] Monetary benefits are rounded to two significant digits.

[B] Monetary benefits are adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030).

[C] Premature mortality associated with ozone is not separately included in this analysis. It is assumed that the C-R function for premature mortality captures both PM mortality benefits and any mortality benefits associated with other air pollutants. Also note that the valuation assumes the 5 year distributed lag structure described earlier. Results reflect the use of two different discount rates; a 3% rate which is recommended by EPA's Guidelines for Preparing Economic Analyses (US EPA, 2000c), and 7% which is recommended by OMB Circular A-94 (OMB, 1992).

[D] Respiratory hospital admissions for PM includes admissions for COPD, pneumonia, and asthma.

[E] Cardiovascular hospital admissions for PM includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[F] Respiratory hospital admissions for ozone includes admissions for all respiratory causes and subcategories for COPD and pneumonia.

[G] B represents the monetary value of the unmonetized health and welfare benefits. A detailed listing of unquantified PM, ozone, CO, and NMHC related health effects is provided in Table XI-B.1.

To gain further understanding into the public health impact of the modeled change in air quality associated with the preliminary control options, we examined the incidence of health effects occurring in three age groups: children (0-17), adults (18-64), and elderly adults (65 and older). Certain endpoints occur only in a subset of age groups, so not all endpoints are reported for all age groups. Two sets of age group estimates were calculated. The first is based on the specific age ranges examined in the epidemiological studies, for example, the Dockery et al (1996) acute bronchitis study focused on a sample population aged 8 to 12. These are the estimates that were used in deriving total incidences as reported in Table 9A.9. In many cases however, the study populations were defined as a matter of convenience or due to data availability, rather than due to any biological factor that would restrict the effect to the specific age group. In order to gain a more complete understanding of the potential magnitude of the health impact in the entire population, we calculate a separate estimate including the health impact on all population within an age group. The two sets of age specific incidence estimates are provided in Table 9A-32. Note that for premature mortality, we chose not to extend the estimates based on long-term exposure to children, even though there is some evidence that PM exposure has mortality impacts in this age group (see Woodruff et al., 1997). The short-term exposure studies used in the alternative estimate include all ages, and thus provide an estimate of mortality benefits occuring in children.

We also estimated respiratory symptoms and attacks occurring the asthmatic population, based on the studies defined in Table 9A-22. As with the age group specific estimates, we provide two sets of calculations, one based on applying the C-R function only to the specific population subgroup included in a study's sample population, and another based on applying the C-R function to all populations within a broader population. The two sets of asthma symptom incidences are provided in Table 9A-33. As noted earlier in this appendix, the asthma symptom estimates provided in Table 9A-33 are not additive to the total benefits presented in Table 9A-31. They are provided to show the specific impacts on an especially susceptible subpopulations. Also note that the estimates are not additive even within the table. We have grouped the estimates based on the type of symptoms measured, but there is the potential for considerable overlap. However, these estimates provide an illustration of the consistency of the effects across studies and populations of asthmatics.

Table 9A-32.
Reductions in Incidence of Health Endpoints by Age Group[A]

Endpoint/Age Group	Pollutants	Avoided Incidence - Study Population Only (cases/year)		Avoided Incidence - Total Age Group Population (cases/year)	
		2020	2030	2020	2030
Children, 0-17					
Premature mortality[B] - Alternative estimate: Short-term exposure	PM	20	30	20	30
Hospital Admissions - Respiratory Causes[C]	O_3 and PM	240	570	240	570
Emergency Room Visits for Asthma	O_3 and PM	4,300	6,500	4,300	6,500
Acute bronchitis	PM	10,000	16,000	31,000	47,000
Lower respiratory symptoms	PM	110,000	170,000	220,000	330,000
Upper respiratory symptoms in asthmatic children	PM	92,000	120,000	430,000	660,000
School absence days (children, age 6-11)	O_3				
Adults, 18-64					
Premature mortality[B] - Base estimate: Long-term exposure Alternative estimate: Short-term exposure	 PM PM	 1,400 770	 1,800 1,000	 1,500 770	 1,900 1,000
Chronic bronchitis	PM	7,600	11,000	8,300	12,000
Non-fatal myocardial infarctions	PM	3,900	5,300	3,900	5,300
Hospital admissions – Cardiovascular[D]	PM	1,100	1,450	1,100	1,450
Hospital admissions – Respiratory[E]	PM	490	660	490	660
Work loss days	PM	780,000	1,100,000	780,000	1,100,000
Minor restricted activity days	O_3 and PM	4,600,000	6,600,000	4,600,000	6,600,000
Adults, 65 and older					
Premature mortality[B] - Base estimate: Long-term exposure Alternative estimate: Short-term exposure	 PM PM	 4,900 2,900	 9,100 5,500	 4,900 2,900	 9,100 5,500
Chronic Bronchitis	PM	1,000	1,900	1,000	1,900
Non-fatal Myocardial Infarctions	PM	6,600	12,000	6,600	12,000
Hospital Admissions - Cardiovascular Causes	PM	2,300	4,300	2,300	4,300
Hospital Admissions – Respiratory Causes	O_3 and PM	2,700	5,700	2,700	5,700

[A] Incidences are rounded to two significant digits.

[B] Premature mortality associated with ozone is not separately included in this analysis

[C] Respiratory hospital admissions for children include ICD codes 493, 464.4, 466, and 480-486).

[D] Cardiovascular hospital admissions for adults includes total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[E] Respiratory hospital admissions for adults include admissions for all respiratory causes and subcategories for COPD and pneumonia, and asthma.

Table 9A-33.
Reductions in Incidence of Respiratory Symptoms in the Asthmatic Population

Endpoint (Study population)	Study	Pollutant	Avoided Incidence - Study Population Only (cases/year)		Avoided Incidence - Total Age Group Population (cases/year)	
			2020	2030	2020	2030
Asthma Attack Indicators[A]						
Shortness of Breath (African American asthmatics, 8-13)	Ostro et al. (2001)	PM	10,000	15,000	30,000	45,000
Cough (African American asthmatics, 8-13)	Ostro et al. (2001)	PM	21,000	31,000	63,000	94,000
Wheeze (African American asthmatics, 8-13)	Ostro et al. (2001)	PM	16,000	24,000	49,000	74,000
Asthma Exacerbation – one or more symptoms (Asthmatics, 5-13)	Yu et al. (2000)	PM	400,000	530,000	630,000	950,000
Cough (Asthmatics, 6-13)	Vedal et al. (1998)	PM	180,000	240,000	320,000	490,000
Other symptoms/illness endpoints						
Upper Respiratory Symptoms (Asthmatics 9-11)	Pope et al. (1991)	PM	92,000	120,000	430,000	660,000
Moderate or Worse Asthma (Asthmatics, all ages)	Ostro et al. (1991)	PM	86,000	121,000	86,000	121,000
Acute Bronchitis (Asthmatics, 9-15)	McConnell et al. (1999)	PM	3,000	4,700	7,000	11,000
Chronic Phlegm (Asthmatics, 9-15)	McConnell et al. (1999)	PM	7,500	12,000	18,000	27,000
Asthma Attacks (Asthmatics, all ages)	Whittemore and Korn (1980)	PM	130,000	160,000	130,000	160,000

[A] Note that these are not necessarily independent symptoms. Combinations of these symptoms may occur in the same individuals, so that the sum of the avoided incidences is not necessarily equal to the sum of the affected populations. Also, some studies cover the same or similar endpoints in overlapping populations. For example, the Vedal et al (1998) and Ostro et al (2000) studies both examine cough. The Ostro et al (2000) estimate examines a more restricted population than Veal et al (1998), so estimates should be combined with caution.

9A.5 Discussion

This analysis has estimated the health and welfare benefits of reductions in ambient concentrations of particulate matter resulting from reduced emissions of NOx, SO_2, VOC, and diesel PM from nonroad diesel engines. The result suggests there will be significant health and welfare benefits arising from the regulation of emissions from nonroad engines in the U.S. Our estimate that 11,000 premature mortalities would be avoided in 2030, when emission reductions from the regulation are fully realized, provides additional evidence of the important role that pollution from the nonroad sector plays in the public health impacts of air pollution.

We provide sensitivity analyses in Appendix 9B to examine key modeling assumptions. In addition, there are other uncertainties that we could not quantify, such as the importance of unquantified effects and uncertainties in the modeling of ambient air quality. Inherent in any analysis of future regulatory programs are uncertainties in projecting atmospheric conditions, source-level emissions, and engine use hours, as well as population, health baselines, incomes, technology, and other factors. The assumptions used to capture these elements are reasonable based on the available evidence. However, data limitations prevent an overall quantitative estimate of the uncertainty associated with estimates of total economic benefits. If one is mindful of these limitations, the magnitude of the benefit estimates presented here can be useful information in expanding the understanding of the public health impacts of reducing air pollution from nonroad engines.

The U.S. EPA will continue to evaluate new methods and models and select those most appropriate for the estimation the health benefits of reductions in air pollution. It is important to continue improving benefits transfer methods in terms of transferring economic values and transferring estimated C-R functions. The development of both better models of current health outcomes and new models for additional health effects such as asthma and high blood pressure will be essential to future improvements in the accuracy and reliability of benefits analyses (Guo et al., 1999; Ibald-Mulli et al., 2001). Enhanced collaboration between air quality modelers, epidemiologists, and economists should result in a more tightly integrated analytical framework for measuring health benefits of air pollution policies. The Agency welcomes comments on how we can improve the quantification and monetization of health and welfare effects and on methods for characterizing uncertainty in our estimates.

Appendix 9A References

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APPENDIX 9B: Sensitivity Analyses of Key Parameters in the Benefits Analysis

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The Base Estimate is based on our current interpretation of the scientific and economic literature. That interpretation requires judgments regarding the best available data, models, and modeling methodologies; and assumptions we consider most appropriate to adopt in the face of important uncertainties. The majority of the analytical assumptions used to develop the Base Estimate have been reviewed and approved by EPA's Science Advisory Board (SAB). However, we recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that reasonable alternative assumptions exist for some inputs to the analysis, such as the mortality C-R functions. In Chapter 9 and Appendix 9A, we provide an Alternative estimate to show the impact of combining several alternative assumptions about the estimation and valuation of mortality impacts, as well as the valuation of chronic bronchitis. This appendix provides additional senstivity analyses, relative to both the Base and Alternative estimates.

We supplement our Base Estimate of benefits with a series of sensitivity calculations that make use of other sources of concentration-response and valuation data for key benefits categories. These sensitivity calculations are conducted relative to the Base Estimate and not for the Alternative Estimate. The sensitivity estimates can be used to answer questions like “What would total benefits be if we were to value avoided incidences of premature mortality using the age-dependent VSL rather than the age-independent VSL approach?” These estimates examine sensitivity to both valuation issues (e.g. the correct value for a statistical life saved) and for physical effects issues (e.g., possible recovery from chronic illnesses). These estimates are not meant to be comprehensive. Rather, they reflect some of the key issues identified by EPA or commentors as likely to have a significant impact on total benefits. Individual adjustments in the tables should not be added together without addressing potential issues of overlap and low joint probability among the endpoints. Additional sensitivity estimates are provided in the benefits TSD (Abt Associates, 2003).

We supplement the Alternative Estimate of benefits with a set of senstivity analyes that explore the impacts of changing two elements: the starting point value of a stastistical life used to derive the value of a statistical life year, and the assumed number of life years gained for premature mortalities avoided from reductions in short-term exposures to $PM_{2.5}$.

9B.1 Premature Mortality—Long term exposure

Given current evidence regarding their value, reductions in the risk of premature mortality is the most important PM-related health outcome in terms of contribution to dollar benefits. There are four important analytical assumptions that may significantly impact the estimates of the number and valuation of avoided premature mortalities. These include selection of the C-R function, structure of the lag between reduced exposure and reduced mortality risk, the relationship between age and VSL, and effect thresholds. Results of this set of sensitivity analyses are presented in Table 9B.1.

9B.1.1 Alternative C-R Functions

Although we used the Krewski, et al. (2000) mean-based ("PM2.5(DC), All Causes") model exclusively to derive our Base Estimate of avoided premature mortality, this analysis also examined the sensitivity of the benefit results to the selection of alternative C-R functions for premature mortality. We used two sources of alternative C-R functions for this sensitivity analysis: (1) an extended analysis of the American Cancer Society data, reported in Table 2 of Pope et al. (2002); and (2) the Krewski et al. "Harvard Six Cities" estimate. The Pope et al (2002) analysis provides estimates of the relative risk for all-cause, cardiopulmonary, and lung cancer mortality, using a longer followup period relative to the original data examined in Krewski et al (2000). The SAB has noted that "the [Harvard Six Cities] study had better monitoring with less measurement error than did most other studies" (EPA-SAB-COUNCIL-ADV-99-012, 1999). However, the Krewski-Harvard Six Cities study had a more limited geographic scope (and a smaller study population) than the Krewski-ACS study. The demographics of the ACS study population, i.e., largely white and middle-class, may also produce a downward bias in the estimated PM mortality coefficient, because short-term studies indicate that the effects of PM tend to be significantly greater among groups of lower socioeconomic status. The Krewski-Harvard Six Cities study also covered a broader age category (25 and older compared to 30 and older in the ACS study) and followed the cohort for a longer period (15 years compared to 8 years in the ACS study). The HEI commentary notes that “the inherent limitations of using only six cities, understood by the original investigators, should be taken into account when interpreting the results of the Six Cities Study.” We emphasize, that based on our understanding of the relative merits of the two datasets, the Krewski, et al. (2000) ACS model based on mean $PM_{2.5}$ levels in 63 cities is the most appropriate model for analyzing the premature mortality impacts of the nonroad standards. It is thus used for our primary estimate of this important health effect. In addition to these alternative C-R functions, a broader set of alternative mortality C-R functions is examined in the benefits TSD (Abt Associates, 2003).

9B.1.2 Alternative Lag Structures

As noted by the SAB (EPA-SAB-COUNCIL-ADV-00-001, 1999), “some of the mortality effects of cumulative exposures will occur over short periods of time in individuals with compromised health status, but other effects are likely to occur among individuals who, at baseline, have reasonably good health that will deteriorate because of continued exposure. No animal models have yet been developed to quantify these cumulative effects, nor are there epidemiologic studies bearing on this question.” However, they also note that “Although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no a lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population.” In the primary analysis, based on SAB advice, we assume that mortality occurs over a five year period, with 25 percent of the deaths occurring in the first year, 25 percent in the second year, and 16.7 percent in each of the third, fourth, and fifth years. Readers should note that the selection of a 5 year lag is not supported by any scientific literature on PM-related mortality (NRC 2002). Rather it is intended to be a best guess at the appropriate distribution of avoided incidences of PM-related mortality.

Although the SAB recommended the five-year distributed lag be used for the primary analysis, the SAB has also recommended that alternative lag structures be explored as a sensitivity analysis (EPA-SAB-COUNCIL-ADV-00-001, 1999). Specifically, they recommended an analysis of 0, 8, and 15 year lags. The 0 year lag is representative of EPA's assumption in previous RIAs. The 8 and 15 year lags are based on the study periods from the Pope, et al. (1995) and Dockery, et al. (1993) studies, respectively[ee]. However, neither the Pope, et al. or Dockery, et al studies assumed any lag structure when estimating the relative risks from PM exposure. In fact, the Pope, et al. and Dockery, et al. studies do not contain any data either supporting or refuting the existence of a lag. Therefore, any lag structure applied to the avoided incidences estimated from either of these studies will be an assumed structure. The 8 and 15 year lags implicitly assume that all premature mortalities occur at the end of the study periods, i.e. at 8 and 15 years. It is important to keep in mind that changes in the lag assumptions do not change the total number of estimated deaths, but rather the timing of those deaths.

The estimated impacts of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Krewski et al ACS C-R function) are presented in Table 9B.2. These estimates are based on the value of statistical lives saved approach, i.e. $6 million per incidence, and are presented for both a 3 and 7 percent discount rate over the lag period. Even with an extreme lag assumption of 15 years, benefits are reduced by less than half relative to the no lag and primary (5-year distributed lag) benefit estimates.

9B.1.3 Age and VSL

The relationship between age and willingness to pay for mortality risk reductions has been the subject of much research over the past several years. Recent research in the U.S. has not found a significant reduction in WTP for risk reductions in older populations (Smith et al. 2002; Alberini et al., 2002; Schultze, 2002). Studies outside of the U.S. have found a signficant reduction in WTP for older individuals, ranging from 10 percent (Jones-Lee, 1993) to around 35 percent (Alberini et al. 2002) for a 70 year old, relative to a 40 year old. Around 80 percent of the deaths projected to be avoided from reduced exposure to PM in 2020 and 2030 are in populations over 65. As such, the assumption that populations of all ages have the same VSL can have a significant impact on the total benefits. For this sensitivity analysis, the method we use to account for age differences is to adjust the base $6.1 million VSL based on ratios of VSL's for specific ages to the VSL for a 40 year old individual. There are several potential sources for these ratios.

[EE] Although these studies were conducted for 8 and 15 years, respectively, the choice of the duration of the study by the authors was not likely due to observations of a lag in effects, but is more likely due to the expense of conducting long-term exposure studies or the amount of satisfactory data that could be collected during this time period.

Two Jones-Lee studies to provide evidence of strong and weak age effects on WTP for mortality risk reductions. The ratios based on Jones-Lee (1989), as summarized in U.S. EPA (2000), suggest a steep inverted U shape between age and VSL, with the VSL for a 70 year old at 63 percent of that for a 40 year old, and the VSL for an 85 year old at 7 percent of that for 40 year old. The ratios based on Jones-Lee (1993) and summarized in U.S. EPA (2000), suggest a much flatter inverted U shape, with the VSL for a 70 year old at 92 percent of that for a 40 year old, and the VSL for an 85 year old at 82 percent of that for a 40 year old. Recent analyses conducted in Canada and the U.S. (Alberini et al, 2002; Krupnick et al, 2002) found mixed results. The Canadian analysis found around a 35 percent reduction in VSL for respondents over age 70, but the U.S. analysis found no significant differences in VSL across ages. The wide range of age-adjustment ratios, especially at older ages demonstrates the difficulty in making these kinds of adjustments. We select the recent Krupnick et al results for Canada as the basis for calculating age-specific VSL, because it uses state of the art stated preference methods and reflects more current preferences. Krupnick (2002) may understate the effect of age because they only control for income and do not control for wealth. While there is no empirical evidence to support or reject hypotheses regarding wealth and observed WTP, WTP for additional life years by the elderly may in part reflect their wealth position vis a vis middle age respondents.

We note that our Base estimate is the most consistent with current evidence on U.S. preferences for risk reduction in older populations. To calculate benefits using the age-adjusted VSL, we first calculate the number of avoided premature mortalities in each age category, and then apply the age adjusted VSL to the appropriate incidences in each age category.

9B.1.4 Thresholds

Although the consistent advice from EPA's Science Advisory Board has been to model premature mortality associated with PM exposure as a non-threshold effect, that is, with harmful effects to exposed populations regardless of the absolute level of ambient PM concentrations, some analysts have hypothesized the presence of a threshold relationship. The nature of the hypothesized relationship is that there might exist a PM concentration level below which further reductions no longer yield premature mortality reduction benefits. EPA does not necessarily endorse any particular threshold and, as discussed in section 9A, virtually every study to consider the issue indicates absence of a threshold.

We construct a senstivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. The sensitivity analysis illustrates how our estimates of the number of premature mortalities in the Base Estimate might change under a range of alternative assumptions for a PM mortality threshold. If, for example, there were no benefits of reducing PM concentrations below the $PM_{2.5}$ standard of 15 µg/m3, our estimate of the total number of avoided PM-related premature mortalities in 2030 would be reduced by approximately 70 percent, from approximately 11,000 annually to approximately 3,200 annually. However, this type of cutoff is unlikely, as supported by the recent NRC report, which stated that “for pollutants such as PM10 and PM2.5, there is no evidence for any departure of linearity in the observed range of exposure, nor any indiciation of a threshold. (NRC, 2002)”

Another possible senstivity analysis which we have not conducted at this time might examine the potential for a nonlinear relationship at lower exposure levels.

One important assumption that we adopted for the threshold sensitivity analysis is that no adjustments are made to the shape of the C-R function above the assumed threshold. Instead, thresholds were applied by simply assuming that any changes in ambient concentrations below the assumed threshold have no impacts on the incidence of premature mortality. If there were actually a threshold, then the shape of the C-R function would likely change and there would be no health benefits to reductions in PM below the threshold. However, as noted by the NRC, “the assumption of a zero slope over a portion of the curve will force the slope in the remaining segment of the positively sloped concentration-response function to be greater than was indicated in the original study” and that “the generation of the steeper slope in the remaining portion of the concentration-response function may fully offset the effect of assuming a threshold.” The NRC suggested that the treatment of thresholds should be evaluated in a formal uncertainty analysis. As noted in earlier sections, EPA is developing a formal uncertainty analysis processs which we intend to at least partially implement for the analysis of the final rule.

Table 9B-1.
Sensitivity of Estimates to Alternative Assumptions Regarding Quantification of Mortality Benefits

Description of Sensitivity Analysis		Avoided Incidences[A]		Value (million 2000$)[B]	
		2020	2030	2020	2030
Alternative Concentration-Response Functions for PM-related Premature Mortality					
Pope/ACS Study (2002)					
All Cause		5,400	9,500	$41,000	$74,000
Lung Cancer		*740*	*1,300*	*$5,600*	*$9,900*
Cardiopulmonary		*4,000*	*7,200*	*$30,000*	*$55,000*
Krewski/Harvard Six-city Study		18,000	32,000	$140,000	$240,000
Alternative Lag Structures for PM-related Premature Mortality (3% discount rate)					
None	Incidences all occur in the first year	6,200	11,000	$49,000	$89,000
8-year	Incidences all occur in the 8th year	6,200	11,000	$40,000	$72,000
15-year	Incidences all occur in the 15th year	6,200	11,000	$33,000	$59,000
Alternative Mortality Risk Valuation Based on Age Specific VSL					
VSL applied to statistical deaths avoided in populations 70 and over equal to 65% of VSL for avoided deaths in populations under 70		6,200	11,000	$36,000	$63,000
Alternative Thresholds					
No Threshold (base estimate)		6,200	11,000	$47,000	$85,000
5		6,200	11,000	$47,000	$85,000
10		5,000	9,400	$38,000	$72,000
15		1,300	3,200	$10,000	$25,000
20		500	1,000	$3,800	$8,000
25		150	430	$1,100	$3,300

[A] Incidences rounded to two significant digits.
[B] Dollar values rounded to two significant digits.

The results of these sensitivity analysis demonstrate that choice of C-R function can have a large impact on benefits, potentially doubling the effect estimate if the C-R function is derived from the HEI reanalysis of the Harvard Six-cities data (Krewski et al., 2000). Due to discounting of delayed benefits, the lag structure may also have a large impact on monetized benefits, reducing benefits by 30 percent if an extreme assumption that no effects occur until after 15 years is applied. If no lag is assumed, benefits are increased by around five percent. The threshold analysis indicates that approximately 80 percent of the premature mortality related benefits are due to changes in $PM_{2.5}$ concentrations occurring above 10 $\mu g/m^3$, and around 20 percent are due to changes above 15 $\mu g/m^3$, the current $PM_{2.5}$ standard.

9B.2 Premature Mortality—Short term exposure

The Alternative estimate is based on several key parameters, including the starting point value of a statistical life used to calculate the value of a statistical life year and the number of life years gained for each premature death from air pollution avoided. This set of senstivity analyses examines how changes to each of these assumptions will impact the Alternative Estimate. Two alternative values are examined for each parameter. For the starting VSL, values of $1 million and $10 million are used. For the number of life years gained, values of 1 year and 14 years are used. Results are presented in Table 9B-2. We performed the analysis below using a 3% discount rate. We will also be conducting a similar analysis using a 7% discount rate and including this information in the public docket.

Table 9B-2.
Impacts of VSL and Life Years Gained Assumptions on Alternative Benefits Estimates

Alternative Calculation		**Description of Estimate**	**Impact on Alternative Benefit Estimate (3% discount rate) (Billion 2000$)**	
			2020	2030
1	$1 million VSL	Derivation of VSLY based on starting VSL of $1 million	-$5.3 (-48%)	-$9.8 (-52%)
2	$10 million VSL	Derivation of VSLY based on starting VSL of $10 million	+$12 (+112%)	+$23 (+121%)
3	1 life year gained	Assumes each premature mortality avoided due to reductions in short-term exposures to $PM_{2.5}$ results in 1 life year gained.	-$5.5 (-50%)	-$10 (-54%)
4	14 life years gained	Assumes each premature mortality avoided due to reductions in short-term exposures to $PM_{2.5}$ results in 14 life years gained.	+$13 (+116%)	+$24 (+126%)

9B.3 Other Health Endpoint Sensitivity Analyses

9B.3.1 Overlapping Endpoints

In Appendix 9A, we estimated the benefits of the modeled preliminary control options using the most comprehensive set of endpoints available. For some health endpoints, this meant using a concentration-response (C-R) function that linked a larger set of effects to a change in pollution, rather than using C-R functions for individual effects. For example, for premature mortality, we selected a C-R function that captured reductions in incidences due to long-term exposures to ambient concentrations of particulate matter, assuming that most incidences of mortality associated with short-term exposures would be captured. In addition, the long-term exposure premature mortality C-R function for $PM_{2.5}$ is expected to capture at least some of the mortality effects associated with exposure to ozone.

In order to provide the reader with a fuller understanding of the health effects associated with reductions in air pollution associated with the preliminary control options, this set of sensitivity estimates examines those health effects which, if included in the primary estimate, could result in double-counting of benefits. For some endpoints, such as ozone mortality, additional research is needed to provide separate estimates of the effects for different pollutants, i.e. PM and ozone. These supplemental estimates should not be considered as additive to the total estimate of benefits, but illustrative of these issues and uncertainties. Sensitivity estimates included in this appendix include premature mortality associated with short-term exposures to ozone, and acute respiratory symptoms in adults. Results of this set of sensitivity analyses are presented in Table 9B-3.

The benefit estimates presented in the Alternative estimate in Tables 9A-30 and 9A-31 of Appendix 9A do not capture any additional short-term mortality impacts related to changes in exposure to ambient ozone. A recent analysis by Thurston and Ito (2001) reviewed previously published time series studies of the effect of daily ozone levels on daily mortality and found that previous EPA estimates of the short-term mortality benefits of the ozone NAAQS (U.S. EPA, 1997) may have been underestimated by up to a factor of two. The authors hypothesized that much of the variability in published estimates of the ozone/mortality effect could be explained by how well each model controlled for the influence of weather. Weather is a potentially important confounder of the ozone/mortality effect, and Thurston and Ito found that earlier studies using less sophisticated approaches to controlling for weather consistently under-predicted the ozone/mortality effect. They found that models incorporating a non-linear temperature specification appropriate for the "U-shaped" nature of the temperature/mortality relationship (i.e., increased deaths at both very low and very high temperatures) produced ozone/mortality effect estimates that were both more strongly positive (a two percent increase in relative risk over the pooled estimate for all studies evaluated) and consistently statistically significant. Further accounting for the interaction effects between temperature and relative humidity produced even more strongly positive results. Inclusion of a PM index to control for PM/mortality effects had little effect on these results, suggesting an ozone/mortality relationship independent of that for PM. However, most of the studies examined by Ito and Thurston only controlled for PM_{10} or broader measures of particles and did not directly control for $PM_{2.5}$. As such, there may still be potential for confounding of $PM_{2.5}$ and ozone mortality effects, as ozone and $PM_{2.5}$ are highly correlated during summer months in some areas. In its September 2001 advisory on the draft analytical blueprint for the second Section 812 prospective analysis, the SAB cited the Thurston and Ito study as a significant advance in understanding the effects of ozone on daily mortality and recommended re-evaluation of the ozone mortality endpoint for inclusion in the next prospective study (EPA-SAB-COUNCIL-ADV-01-004, 2001). Thus, recent evidence suggests that by not including an estimate of reductions in short-term mortality due to changes in ambient ozone, both the Base and Alternative Estimates may underestimate the benefits of implementation of the Nonroad Diesel Engine rule.

The ozone mortality sensitivity estimate is calculated using results from four U.S. studies (Ito and Thurston, 1996; Kinney et al., 1995; Moolgavkar et al., 1995; and Samet et al., 1997), based on the assumption that demographic and environmental conditions on average would be more similar between these studies and the conditions prevailing when the nonroad standards are implemented. We combined these studies using probabilistic sampling methods to estimate the impact of ozone on mortality incidence. The technical support document for this analysis provides additional details of this approach (Abt Associates, 2003). The estimated incidences of short-term premature mortality are valued using the value of statistical lives saved method, as described in Appendix 9A.

Table 9B-2.
Sensitivity Estimates for Potentially Overlapping Endpoints[A]

Description of Sensitivity Analysis	**Avoided Incidences**		**Monetized Value (Million 2000$)**	
	2020	**2030**	**2020**	**2030**
Mortality from Short-term Ozone Exposure[B]				
Ito and Thurston (1996)	440	1,000	$3,500	$8,100
Kinney et al. (1995)	0	0	$0	$0
Moolgavkar et al. (1995)	77	240	$620	$1,900
Samet et al. (1997)	120	360	$960	$2,900
Pooled estimate (random effects weights)	**94**	**280**	**$750**	**$2,300**
Any of 19 Acute Respiratory Symptoms, Adults 18-64 (Krupnick et al. 1990)				
Ozone	1,500,000	2,800,000	$38	$71
PM	14,000,000	19,000,000	$340	$490

[A] All estimates rounded to two significant digits.

[B] Mortality valued using Base estimate of $6.3 million per premature statistical death, adjusted for income growth.

9B.3.2 Alternative and Supplementary Estimates

We also examine how the value for individual endpoints or total benefits would change if we were to make a different assumption about specific elements of the benefits analysis. Specifically, in Table 9B.3, we show the impact of alternative assumptions about other parameters, including infant mortality associated with exposure to PM, treatment of reversals in chronic bronchitis as lowest severity cases, effects of ozone on new incidences of chronic asthma, alternative C-R function for chronic bronchitis, alternative C-R functions for PM hospital and ER admissions, valuation of residential visibility, valuation of recreational visibility at Class I areas outside of the study regions examined in the Chestnut and Rowe (1990a, 1990b) study, and valuation of household soiling damages.

Table 9B-3.
Additional Parameter Sensitivity Analyses

Alternative Calculation		Description of Estimate	Impact on Base Benefit Estimate (3% discount rate) (million 2000$)	
			2020	2030
1	Infant Mortality	Avoided incidences of mortality in infants are estimated using the Woodruff et al (1997) C-R function. The number of avoided incidences of infant mortality is 35 in 2020 and 52 in 2030	+$270 (+0.5%)	+$400 (+0.4%)
2	Chronic Asthma[a]	Avoided incidences of chronic asthma are estimated using the McDonnell, et al. (1999) C-R function relating annual average ozone levels to new incidences of asthma in adult males over the age of 27. The number of avoided incidences of chronic asthma is 1,200 in 2020 and 2,400 in 2030	+$36 (+0.1%)	+$74 (+0.1%)
3	Reversals in chronic bronchitis treated as lowest severity cases	Instead of omitting cases of chronic bronchitis that reverse after a period of time, they are treated as being cases with the lowest severity rating. The number of avoided chronic bronchitis incidences in 2020 increases from 4,300 to 8,000 (87%). The increase in 2030 is from 6,500 to 12,000 (87%).	+$730 (+1.4%)	+$1,100 (+1.2%)
4	Value of visibility changes in all Class I areas	Values of visibility changes at Class I areas in California, the Southwest, and the Southeast are transferred to visibility changes in Class I areas in other regions of the country.	+$640 (+1.2%)	+$970 (+1.1%)
5	Value of visibility changes in Eastern U.S. residential areas	Value of visibility changes outside of Class I areas are estimated for the Eastern U.S. based on the reported values for Chicago and Atlanta from McClelland et al. (1990).	+$700 (+1.3%)	+$1,100 (+1.1%)
6	Value of visibility changes in Western U.S. residential areas	Value of visibility changes outside of Class I areas are estimated for the Western U.S. based on the reported values for Chicago and Atlanta from McClelland et al. (1990).	+$530 (+1.0%)	+$830 (+0.9%)
7	Household soiling damage	Value of decreases in expenditures on cleaning are estimated using values derived from Manuel, et al. (1983).	+$170 (+0.3%)	+$260 (+0.3%)

[a] While no causal mechanism has been identified linking new incidences of chronic asthma to ozone exposure, two epidemiological studies shows a statistical association between long-term exposure to ozone and incidences of chronic asthma in exercising children and some non-smoking men (McConnell, 2002; McDonnell, et al., 1999).

The estimated effect of PM exposure on premature mortality in post neo-natal infants (row 1 of Table 9B.3) is based on a single U.S. study (Woodruff et al.,1997) which, on SAB advice, was deemed too uncertain to include in the primary analysis. Adding this endpoint to the primary benefits estimate would result in an increase in total benefits. The infant mortality estimate indicates that exclusion of this endpoint does not have a large relative impact, either in terms of incidences (35 in 2020 and 52 in 2030) or monetary value (approximately $270 million in 2020 and $400 million in 2030).

The alternative calculation for the development of chronic asthma (row 2 of Table 9B.3) is estimated using a recent study by McDonnell, et al. (1999) which found a statistical association between ozone and the development of asthma in adult white, non-Hispanic males. Other studies have not identified an association between air quality and the onset of asthma. The McDonnell, et al. prospective cohort study found a statistically significant effect for adult males, but none for adult females. EPA believes it to be appropriate to apply the C-R function to all adult males over age 27 because no evidence exists to suggest that non-white adult males have a lower responsiveness to air-pollution. For other health effects such as shortness of breath, where the study population was limited to a specific group potentially more sensitive to air pollution than the general population (Ostro et al., 1991), EPA has applied the C-R function only to the limited population.

Some commentors have raised questions about the statistical validity of the associations found in this study and the appropriateness of transferring the estimated C-R function from the study populations (white, non-Hispanic males) to other male populations (i.e. African-American males). Some of these concerns include the following: 1) no significant association was observed for female study participants also exposed to ozone; 2) the estimated C-R function is based on a cross-sectional comparison of ozone levels, rather than incorporating information on ozone levels over time; 3) information on the accuracy of self-reported incidence of chronic asthma was collected but not used in estimating the C-R function; 4) the study may not be representative of the general population because it included only those individuals living 10 years or longer within 5 miles of their residence at the time of the study; and 5) the study had a significant number of study participants drop out, either through death, loss of contact, or failure to provide complete or consistent information. EPA believes that while these issues may result in increased uncertainty about this effect, none can be identified with a specific directional bias in the estimates. In addition, the SAB reviewed the study and deemed it appropriate for quantification of changes in ozone concentrations in benefits analyses (EPA-SAB-COUNCIL-ADV-00-001, 1999). EPA recognizes the need for further investigation by the scientific community to confirm the statistical association identified in the McDonnell, et al. study.

Following SAB advice (EPA-SAB-COUNCIL-ADV-00-001, 1999) and consistent with the Section 812 Prospective Report, we quantify this endpoint for the RIA. However, it should be noted that it is not clear that the intermittent, short-term, and relatively small changes in annual average ozone concentrations resulting from this rule alone are likely to measurably change long-term risks of asthma.

Similar to the valuation of chronic bronchitis, WTP to avoid chronic asthma is presented as the net present value of what would potentially be a stream of costs and lower well-being incurred over a lifetime. Estimates of WTP to avoid asthma are provided in two studies, one by Blumenschein and Johannesson (1998) and one by O'Conor and Blomquist (1997). Both studies use the contingent valuation method to solicit annual WTP for an asthma cure (or almost complete cure) from individuals who have been diagnosed as asthmatics. The central estimate of lifetime WTP to avoid a case of chronic asthma among adult males, approximately $25,000, is the average of the present discounted value from the two studies. Details of the derivation of this central estimate from the two studies is provided in the benefits TSD for this RIA (Abt Associates, 2003).

Another important issue related to chronic conditions is the possible reversal in chronic bronchitis incidences (row 3 of Table 9B.3). Reversals are defined as those cases where an individual reported having chronic bronchitis at the beginning of the study period but reported not having chronic bronchitis in follow-up interviews at a later point in the study period. Since, by definition, chronic diseases are long-lasting or permanent, if the disease goes away it is not chronic. However, we have not captured the benefits of reducing incidences of bronchitis that are somewhere in-between acute and chronic. One way to address this is to treat reversals as cases of chronic bronchitis that are at the lowest severity level. These cases thus get the lowest value for chronic bronchitis.

The alternative calculation for recreational visibility (row 4 of Table 9B.3) is an estimate of the full value of visibility in the entire region affected by the nonroad emission reductions. The Chestnut and Rowe study from which the primary valuation estimates are derived only examined WTP for visibility changes in the southeastern portion of the affected region. In order to obtain estimates of WTP for visibility changes in the northeastern and central portion of the affected region, we have to transfer the southeastern WTP values. This introduces additional uncertainty into the estimates. However, we have taken steps to adjust the WTP values to account for the possibility that a visibility improvement in parks in one region, is not necessarily the same environmental quality good as the same visibility improvement at parks in a different region. This may be due to differences in the scenic vistas at different parks, uniqueness of the parks, or other factors, such as public familiarity with the park resource. To take this potential difference into account, we adjusted the WTP being transferred by the ratio of visitor days in the two regions.

The alternative calculations for residential visibility (rows 5 and 6 of Table 9B.3) are based on the McClelland, et al. study of WTP for visibility changes in Chicago and Atlanta. As discussed in Appendix 9A, SAB advised EPA that the residential visibility estimates from the available literature are inadequate for use in a primary estimate in a benefit-cost analysis. However, EPA recognizes that residential visibility is likely to have some value and the McClelland, et al. estimates are the most useful in providing an estimate of the likely magnitude of the benefits of residential visibility improvements.

The alternative calculation for household soiling (row 7 of Table 9B.3) is based on the Manuel, et al. study of consumer expenditures on cleaning and household maintenance. This study has been cited as being "the only study that measures welfare benefits in a manner consistent with economic principals (Desvouges et al., 1998)." However, the data used to estimate household soiling damages in the Manuel, et al. study are from a 1972 consumer expenditure survey and as such may not accurately represent consumer preferences in 2030. EPA recognizes this limitation, but believes the Manuel, et al. estimates are still useful in providing an estimate of the likely magnitude of the benefits of reduced PM household soiling.

9B.4 Income Elasticity of Willingness to Pay

As discussed in Appendix 9A, our estimate of monetized benefits accounts for growth in real GDP per capita by adjusting the WTP for individual endpoints based on the central estimate of the adjustment factor for each of the categories (minor health effects, severe and chronic health effects, premature mortality, and visibility). We examine how sensitive the estimate of total benefits is to alternative estimates of the income elasticities. Table 9B.4 lists the ranges elasticity values used to calculate the income adjustement factors, while Table 9B.5 lists the ranges of corresponding adjustement factors. The results of this sensitivity analysis, giving the monetized benefit subtotals for the four benefit categories, are presented in Table 9B.6.

Consistent with the impact of mortality on total benefits, the adjustment factor for mortality has the largest impact on total benefits. The value of mortality ranges from 81 percent to 150 percent of the primary estimate based on the lower and upper sensitivity bounds on the income adjustment factor. The effect on the value of minor and chronic health effects is much less pronounced, ranging from 93 percent to 111 percent of the primary estimate for minor effects and from 88 percent to 110 percent for chronic effects.

Table 9B-4.
Ranges of Elasticity Values Used to Account for Projected Real Income Growth[A]

Benefit Category	Lower Sensitivity Bound	Upper Sensitivity Bound
Minor Health Effect	0.04	0.30
Severe and Chronic Health Effects	0.25	0.60
Premature Mortality	0.08	1.00
Visibility[B]	--	--

[A] Derivation of these ranges can be found in Kleckner and Neumann (1999) and Chestnut (1997). Cost of Illness (COI) estimates are assigned an adjustment factor of 1.0.

[B] No range was applied for visibility because no ranges were available in the current published literature.

Table 9B-5.
Ranges of Adjustment Factors Used to Account for Projected Real Income Growth[A]

Benefit Category	Lower Sensitivity Bound		Upper Sensitivity Bound	
	2020	2030	2020	2030
Minor Health Effect	1.023	1.025	1.190	1.208
Severe and Chronic Health Effects	1.156	1.170	1.420	1.464
Premature Mortality	1.047	1.052	1.814	1.914
Visibility[B]	--	--	--	--

[A] Based on elasticity values reported in Table 9A-11, US Census population projections, and projections of real gross domestic product per capita.

[B] No range was applied for visibility because no ranges were available in the current published literature.

Table 9B-6.
Sensitivity Analysis of Alternative Income Elasticities[A]

Benefit Category	Lower Sensitivity Bound		Upper Sensitivity Bound	
	2020	2030	2020	2030
Minor Health Effect	$1,400	$2,200	$1,400	$2,200
Severe and Chronic Health Effects (base estimate)	$1,700	$2,600	$2,100	$3,300
Premature Mortality (base estimate)	$38,000	$67,000	$67,000	$130,000
Visibility and Other Welfare Effects[A]	$1,500	$2,400	$1,500	$2,400
Total Benefits	$43,000	$75,000	$72,000	$130,000

[A] All estimates rounded to two significant digits.

[B] No range was applied for visibility because no ranges were available in the current published literature.

Appendix 9B References

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APPENDIX 9C: Visibility Benefits Estimates for Individual Class I Areas

Table 9C-1
Apportionment Factors for 2020 Park Specific Visibility Benefits

PARK	COUNTY	STATE	Percent of 2020 Visibility Benefit Due to Changes in:		
			SO_2	NOx	direct PM
Shenandoah	Lawrence Co	AL	0.428	0.234	0.338
Anaconda-Pintlar W	Cochise Co	AZ	0.337	0.061	0.602
Boundary Waters Canoe A	Gila Co	AZ	0.396	0.054	0.550
Breton W	Gila Co	AZ	0.396	0.054	0.550
Isle Royale	Coconino Co	AZ	0.336	0.053	0.612
Jarbidge W	Apache Co	AZ	0.469	0.049	0.481
Medicine Lake W	Apache Co	AZ	0.469	0.049	0.481
Red Rock Lakes W	Graham Co	AZ	0.302	0.038	0.660
Roosevelt Campobello IP	Pima Co	AZ	0.224	0.061	0.715
Selway-Bitterroot W	Maricopa Co	AZ	0.061	0.014	0.924
Seney W	Coconino Co	AZ	0.336	0.053	0.612
Wolf Island W	Yavapai Co	AZ	0.216	0.140	0.644
Agua Tibia W	Tuolumne Co	CA	0.090	0.580	0.330
Black Canyon of the Gun	San Bernardino Co	CA	0.074	0.158	0.768
Caribou W	Calaveras Co	CA	0.049	0.520	0.432
Chiricahua	Trinity Co	CA	0.367	0.239	0.394
Cucamonga W	Fresno Co	CA	0.051	0.101	0.848
Dome Land W	Mono Co	CA	0.195	0.302	0.504
Flat Tops W	Inyo Co	CA	0.145	0.098	0.757
Grand Canyon	Marin Co	CA	0.060	0.577	0.363
Hoover W	Los Angeles Co	CA	0.099	0.143	0.758
John Muir W	Monterey Co	CA	0.071	0.563	0.366
Kaiser W	San Benito Co	CA	0.057	0.633	0.310
La Garita W	Riverside Co	CA	0.040	0.314	0.646
Mazatzal W	Siskiyou Co	CA	0.469	0.220	0.311
Mesa Verde	San Bernardino Co	CA	0.074	0.158	0.768
Petrified Forest	Del Norte Co	CA	0.518	0.097	0.385
Pine Mountain W	Shasta Co	CA	0.146	0.469	0.385
Pinnacles	Fresno Co	CA	0.051	0.101	0.848
Point Reyes	Lassen Co	CA	0.285	0.347	0.368
Rawah W	Riverside Co	CA	0.040	0.314	0.646
Rocky Mountain	San Diego Co	CA	0.068	0.497	0.435
Saguaro	Shasta Co	CA	0.146	0.469	0.385
San Gabriel W	El Dorado Co	CA	0.050	0.487	0.463
San Gorgino W	Mariposa Co	CA	0.085	0.374	0.541
San Jacinto W	Fresno Co	CA	0.051	0.101	0.848

PARK	COUNTY	STATE	Percent of 2020 Visibility Benefit Due to Changes in: SO$_2$	NOx	direct PM
San Rafael W	Tuolumne Co	CA	0.090	0.580	0.330
Sequoia-Kings	Tulare Co	CA	0.052	0.478	0.470
Sycamore Canyon W	Siskiyou Co	CA	0.469	0.220	0.311
Ventana W	Santa Barbara Co	CA	0.111	0.156	0.733
Yolla-Bolly-Middle-Eel	Tulare Co	CA	0.052	0.478	0.470
Yosemite	Modoc Co	CA	0.277	0.407	0.316
Carlsbad Caverns	San Juan Co	CO	0.522	0.114	0.364
Gila W	Garfield Co	CO	0.335	0.246	0.420
Joyce Kilmer-Slickrock	Routt Co	CO	0.420	0.140	0.440
Kalmiopsis W	Larimer Co	CO	0.449	0.120	0.431
Linville Gorge W	Pitkin Co	CO	0.425	0.098	0.477
Lostwood W	Alamosa Co	CO	0.458	0.097	0.445
Pecos W	Gunnison Co	CO	0.437	0.152	0.411
Presidential Range-Dry	Montezuma Co	CO	0.353	0.077	0.570
Salt Creek W	Montrose Co	CO	0.355	0.175	0.470
Shining Rock W	Summit Co	CO	0.525	0.042	0.433
Wheeler Peak W	Mineral Co	CO	0.589	0.048	0.364
Wichita Mountains W	Larimer Co	CO	0.449	0.120	0.431
Fitzpatrick W	Monroe Co	FL	0.546	0.020	0.434
Glacier Peak W	Wakulla Co	FL	0.535	0.048	0.417
Mount Adams W	Citrus Co	FL	0.416	0.148	0.436
Dolly Sods W	Charlton Co	GA	0.543	0.058	0.399
North Absaroka W	McIntosh Co	GA	0.500	0.052	0.448
Olympic	Edmonson Co	KY	0.415	0.246	0.338
Lye Brook W	Stone Co	MS	0.539	0.112	0.349
Bridger W	Hyde Co	NC	0.344	0.327	0.329
Goat Rocks W	Haywood Co	NC	0.476	0.191	0.333
Otter Creek W	Avery Co	NC	0.516	0.184	0.300
Pasayten W	Graham Co	NC	0.564	0.138	0.298
Bandelier	Sandoval Co	NM	0.426	0.034	0.540
Bosque del Apache W	Rio Arriba Co	NM	0.512	0.047	0.441
Brigantine W	Grant Co	NM	0.414	0.017	0.569
Crater Lake	Chaves Co	NM	0.471	0.094	0.434
Mount Hood W	Mora Co	NM	0.568	0.081	0.352
Mount Washington W	Eddy Co	NM	0.417	0.052	0.531
San Pedro Parks W	Socorro Co	NM	0.409	0.025	0.565
Swanguarter W	Taos Co	NM	0.538	0.057	0.405
Theodore Roosevelt	Lincoln Co	NM	0.603	0.056	0.341
Maroon Bells-Snowmass W	Elko Co	NV	0.311	0.301	0.388
Mount Rainier	Polk Co	TN	0.405	0.237	0.358
North Cascades	Blount Co	TN	0.384	0.184	0.432

PARK	COUNTY	STATE	Percent of 2020 Visibility Benefit Due to Changes in: SO_2	NOx	direct PM
Bob Marshall W	San Juan Co	UT	0.373	0.048	0.579
Gates of the Mountain W	Grand Co	UT	0.354	0.038	0.608
Glacier	San Juan Co	UT	0.373	0.048	0.579
St. Marks W	Washington Co	UT	0.219	0.096	0.685
Voyageurs	Garfield Co	UT	0.295	0.052	0.652
Teton W	Botetourt Co	VA	0.485	0.151	0.364
Yellowstone	Madison Co	VA	0.385	0.316	0.300
Grand Teton NP	Grant Co	WV	0.533	0.190	0.278
Washakie W	Tucker Co	WV	0.568	0.118	0.314

Table 9C-2. Apportionment Factors for 2030 Park Specific Visibility Benefits

PARK	COUNTY	STATE	Percent of 2030 Visibility Benefit Due to Changes in: SO_2	NOx	direct PM
Shenandoah	Lawrence Co	AL	0.376	0.297	0.327
Anaconda-Pintlar W	Cochise Co	AZ	0.313	0.075	0.612
Boundary Waters Canoe A	Gila Co	AZ	0.277	0.048	0.675
Breton W	Gila Co	AZ	0.293	0.089	0.619
Isle Royale	Coconino Co	AZ	0.342	0.107	0.551
Jarbidge W	Apache Co	AZ	0.429	0.069	0.503
Medicine Lake W	Apache Co	AZ	0.429	0.069	0.503
Red Rock Lakes W	Graham Co	AZ	0.188	0.173	0.639
Roosevelt Campobello IP	Pima Co	AZ	0.207	0.072	0.721
Selway-Bitterroot W	Maricopa Co	AZ	0.342	0.107	0.551
Seney W	Coconino Co	AZ	0.057	0.019	0.924
Wolf Island W	Yavapai Co	AZ	0.293	0.089	0.619
Agua Tibia W	Tuolumne Co	CA	0.055	0.571	0.375
Black Canyon of the Gun	San Bernardino Co	CA	0.226	0.407	0.368
Caribou W	Calaveras Co	CA	0.065	0.191	0.745
Chiricahua	Trinity Co	CA	0.129	0.111	0.759
Cucamonga W	Fresno Co	CA	0.039	0.520	0.441
Dome Land W	Mono Co	CA	0.046	0.493	0.461
Flat Tops W	Inyo Co	CA	0.070	0.616	0.314
Grand Canyon	Marin Co	CA	0.070	0.616	0.314
Hoover W	Los Angeles Co	CA	0.049	0.109	0.842
John Muir W	Monterey Co	CA	0.033	0.376	0.591
Kaiser W	San Benito Co	CA	0.049	0.109	0.842
La Garita W	Riverside Co	CA	0.049	0.109	0.842
Mazatzal W	Siskiyou Co	CA	0.116	0.518	0.366

PARK	COUNTY	STATE	Percent of 2030 Visibility Benefit Due to Changes in: SO$_2$	NOx	direct PM
Mesa Verde	San Bernardino Co	CA	0.411	0.270	0.320
Petrified Forest	Del Norte Co	CA	0.411	0.270	0.320
Pine Mountain W	Shasta Co	CA	0.158	0.344	0.498
Pinnacles	Fresno Co	CA	0.043	0.535	0.422
Point Reyes	Lassen Co	CA	0.047	0.663	0.289
Rawah W	Riverside Co	CA	0.053	0.588	0.360
Rocky Mountain	San Diego Co	CA	0.468	0.133	0.399
Saguaro	Shasta Co	CA	0.090	0.175	0.735
San Gabriel W	El Dorado Co	CA	0.065	0.191	0.745
San Gorgino W	Mariposa Co	CA	0.033	0.376	0.591
San Jacinto W	Fresno Co	CA	0.099	0.179	0.722
San Rafael W	Tuolumne Co	CA	0.046	0.493	0.461
Sequoia-Kings	Tulare Co	CA	0.225	0.452	0.323
Sycamore Canyon W	Siskiyou Co	CA	0.116	0.518	0.366
Ventana W	Santa Barbara Co	CA	0.059	0.593	0.348
Yolla-Bolly-Middle-Eel	Tulare Co	CA	0.321	0.292	0.386
Yosemite	Modoc Co	CA	0.073	0.400	0.527
Carlsbad Caverns	San Juan Co	CO	0.312	0.203	0.485
Gila W	Garfield Co	CO	0.464	0.087	0.449
Joyce Kilmer-Slickrock	Routt Co	CO	0.289	0.286	0.425
Kalmiopsis W	Larimer Co	CO	0.407	0.123	0.470
Linville Gorge W	Pitkin Co	CO	0.537	0.074	0.389
Lostwood W	Alamosa Co	CO	0.391	0.103	0.505
Pecos W	Gunnison Co	CO	0.320	0.091	0.589
Presidential Range-Dry	Montezuma Co	CO	0.367	0.180	0.452
Salt Creek W	Montrose Co	CO	0.397	0.156	0.447
Shining Rock W	Summit Co	CO	0.397	0.156	0.447
Wheeler Peak W	Mineral Co	CO	0.471	0.140	0.389
Wichita Mountains W	Larimer Co	CO	0.385	0.188	0.428
Fitzpatrick W	Monroe Co	FL	0.365	0.204	0.431
Glacier Peak W	Wakulla Co	FL	0.503	0.033	0.464
Mount Adams W	Citrus Co	FL	0.497	0.070	0.433
Dolly Sods W	Charlton Co	GA	0.503	0.085	0.412
North Absaroka W	McIntosh Co	GA	0.463	0.082	0.456
Olympic	Edmonson Co	KY	0.365	0.304	0.332
Lye Brook W	Stone Co	MS	0.486	0.166	0.348
Bridger W	Hyde Co	NC	0.515	0.183	0.302
Goat Rocks W	Haywood Co	NC	0.455	0.252	0.293
Otter Creek W	Avery Co	NC	0.436	0.232	0.332
Pasayten W	Graham Co	NC	0.309	0.371	0.320
Bandelier	Sandoval Co	NM	0.389	0.051	0.560

PARK	COUNTY	STATE	Percent of 2030 Visibility Benefit Due to Changes in: SO_2	NOx	direct PM
Bosque del Apache W	Rio Arriba Co	NM	0.374	0.037	0.589
Brigantine W	Grant Co	NM	0.378	0.069	0.553
Crater Lake	Chaves Co	NM	0.387	0.021	0.592
Mount Hood W	Mora Co	NM	0.525	0.100	0.375
Mount Washington W	Eddy Co	NM	0.421	0.124	0.455
San Pedro Parks W	Socorro Co	NM	0.472	0.059	0.469
Swanguarter W	Taos Co	NM	0.481	0.092	0.427
Theodore Roosevelt	Lincoln Co	NM	0.553	0.078	0.369
Maroon Bells-Snowmass W	Elko Co	NV	0.261	0.345	0.394
Mount Rainier	Polk Co	TN	0.359	0.295	0.346
North Cascades	Blount Co	TN	0.345	0.232	0.423
Bob Marshall W	San Juan Co	UT	0.322	0.046	0.632
Gates of the Mountain W	Grand Co	UT	0.265	0.065	0.671
Glacier	San Juan Co	UT	0.337	0.064	0.600
St. Marks W	Washington Co	UT	0.337	0.064	0.600
Voyageurs	Garfield Co	UT	0.190	0.129	0.680
Teton W	Botetourt Co	VA	0.445	0.193	0.361
Yellowstone	Madison Co	VA	0.331	0.387	0.282
Grand Teton NP	Grant Co	WV	0.455	0.275	0.270
Washakie W	Tucker Co	WV	0.487	0.200	0.313

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CHAPTER 10: Economic Impact Analysis

An Economic Impact Analysis (EIA) was prepared to estimate the economic impacts of this proposal on producers and consumers of nonroad engines and equipment and related industries. The Nonroad Diesel Economic Impact Model (NDEIM), developed for this analysis, was used to estimate market-level changes in prices and outputs for affected engine, equipment, fuel, and application markets as well as the social costs and their distribution across economic sectors affected by the program. The basis for this analysis is provided in the Economic Impact Analysis technical support document (RTI, 2003).

10.1 Overview of Results

This section provides a summary of the EPA economic analysis approach and presents an overview of its results. As described below, the overall economic impact of the proposed emission control program on society should be minimal. According to this analysis, the average price of goods and services produced using equipment and fuel affected by the proposal is expected to increase by about 0.02 percent. A more detailed description of this analysis is presented in the following sections of Chapter 10 and the corresponding appendices.

10.1.1 What is an Economic Impact Analysis?

Regulatory agencies conduct economic impact analyses of potential regulatory actions to inform decision makers about the effects of a proposed regulation on society's current and future well-being. In addition to informing decision makers within the Agency, economic impact analyses are conducted to meet the statutory and administrative requirements imposed by Congress and the Executive office. The Clean Air Act requires an economic impact analysis under section 317, while Executive Order 12866–Regulatory Planning and Review requires Executive Branch agencies to perform benefit-costs analysis of all rules it deems to be "significant" (typically over $100 million annual social costs) and submit these analysis to the Office of Management and Budget (OMB) for review. This economic impact analysis estimates the potential market impacts of the proposed rule's compliance costs and provides the associated social costs and their distribution across stakeholders for comparison with social benefits (as presented in Chapter 9).

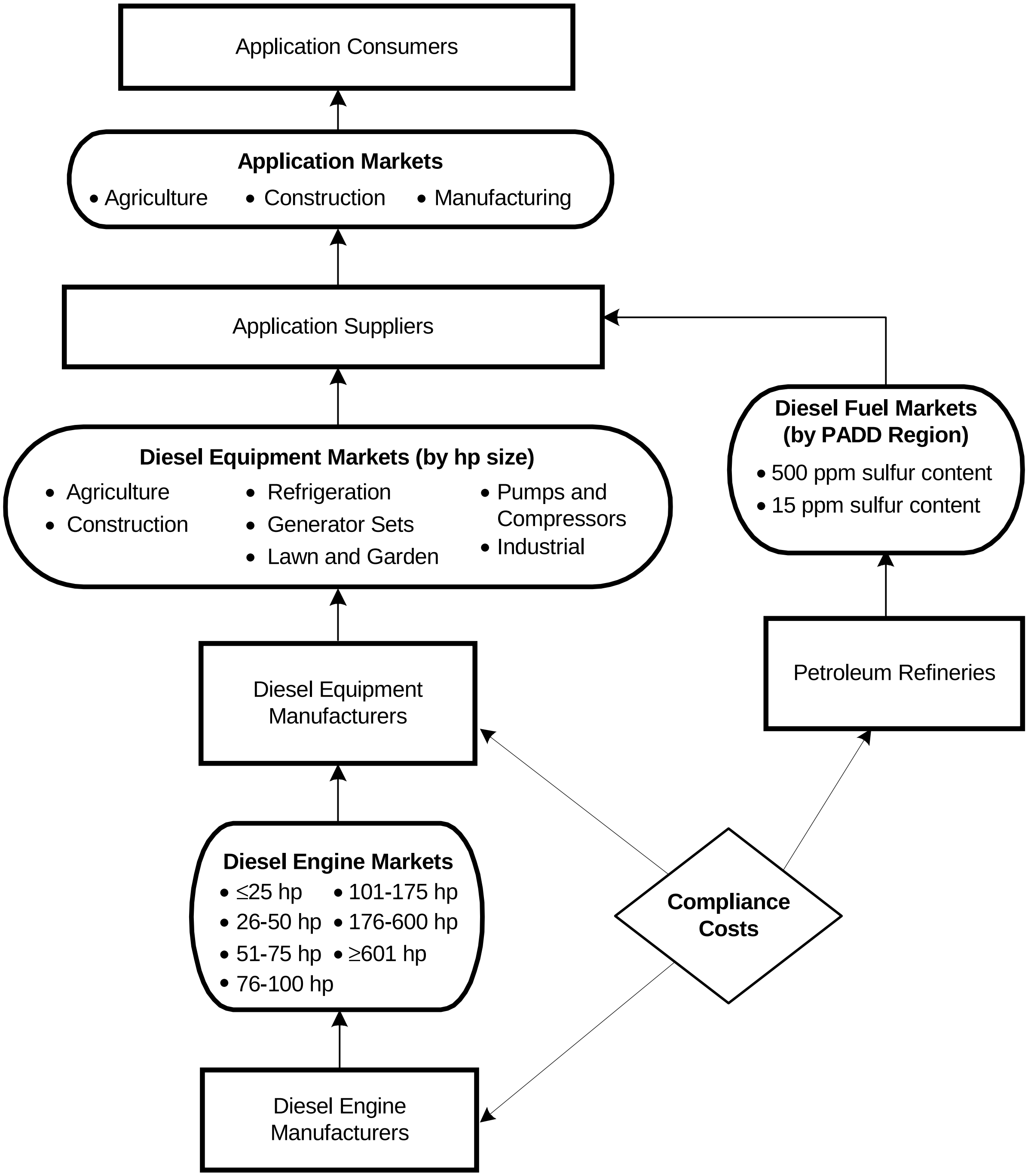
10.1.2 What is EPA's Economic Analysis Approach for this Proposal?

The underlying objective of an EIA is to evaluate the effect of a proposed regulation on the welfare of affected stakeholders and society in general. Using information on the expected compliance costs of the proposed program as presented in Chapters 6 and 7, this EIA explores how the companies that produce nonroad diesel engines, equipment, or fuel may change their production behavior in response to the costs of complying with the standards. It also explores how the consumers who use the affected products may change their purchasing decisions. For example, the construction industry may reduce purchases if the prices of nonroad diesel equipment increase, thereby reducing the volume of equipment sold (or market demand) for such equipment. Alternatively, the construction industry may pass along these additional costs to the consumers of their final goods and services by increasing prices, which would mitigate the potential impacts on the purchases of nonroad diesel equipment.

The Nonroad Diesel Economic Impact Model (NDEIM) developed for this analysis evaluates how producers and consumers are expected to respond to the regulatory costs associated with the proposed emission control program. The conceptual approach is to link significantly affected markets to mimic how compliance costs will potentially ripple through the economy. The NDEIM employs a multi-market partial equilibrium framework to track changes in price and quantity for over 50 integrated product markets. Figure 10.1-1 illustrates the industry segments included in the model and the flow of compliance costs through the economic system.

As shown in Figure 10.1-1, the compliance costs will be directly borne by engine manufacturers, equipment manufacturers, and petroleum refineries. Depending on market characteristics, some or all of these compliance costs will be passed on through the supply chain in the form of higher prices extending to producers and consumers in the application markets (i.e., construction, agriculture, and manufacturing). In this way the proposed rule indirectly affects producers and consumers in all of the related markets included in Figure 10.1-1. For example, the proposed rule will increase the cost of producing nonroad diesel engines. Engine manufacturers will attempt to pass these increased costs on to equipment manufacturers in the form of higher diesel engine prices. Similarly, equipment manufacturers will attempt to pass their direct compliance costs and the increased cost of engines to application manufacturers through higher diesel equipment prices. Petroleum refiners will also attempt to pass their direct compliance costs on to application manufacturers through higher prices for diesel fuel. Finally, application manufacturers will look to pass on the increased equipment and diesel fuel costs to consumers of final application products and services. The NDEIM explicitly models these linkages and estimates the behavioral responses that lead to new equilibrium prices and output for all related markets and the resulting distribution of social costs across affected stakeholders.

Figure 10.1-1
Market Linkages Included in Economic Model



10.1.3 What are the key features of the NDEIM?

The NDEIM is a computer model comprised of a series of spreadsheet modules that define the baseline characteristics of supply and demand for the relevant markets and the relationships between them. The basis for this analysis is provided in the EIA technical support document (RTI, 2003). The model methodology is firmly rooted in applied microeconomic theory and was developed following the *OAQPS Economic Analysis Resource Document* (EPA, 1999). Table 10.1-1 provides a summary of the markets included in the NDEIM, including their baseline characterization and behavioral response parameters (i.e., supply and demand elasticities). These market characteristics are described in more detail in Section 10.3. Based on the specified market linkages, shown in Figure 10.1-1, the model is shocked by applying the engineering compliance cost estimates to the appropriate market suppliers and then numerically solved using an iterative auctioneer approach by "calling out" new prices until a new equilibrium is reached in all markets simultaneously.

The NDEIM uses a multi-market partial equilibrium approach to track changes in price and quantity for 60 integrated product markets, as follows:

- 7 diesel engine markets (less than 25 hp, 26 to 50 hp, 51 to 75 hp, 76 to 100 hp, 101 to 175 hp, 176 to 600 hp, and greater than 600 hp)
- 42 diesel equipment markets (7 horsepower categories within 7 application categories: construction, agricultural, general industrial, pumps and compressors, generator and welder sets, refrigeration and air conditioning, and lawn and garden; there are 7 horsepower/application categories that did not have sales in 2000 and are not included in the model, so the total number of diesel equipment markets is 42, rather than 49)
- 3 application markets (construction, agriculture, and manufacturing)
- 8 nonroad diesel fuel markets (2 sulfur content levels of15 ppm and 500 ppm, for each of 4 PADDs; PADDs 1 and 3 are combined for the purpose of this analysis). It should be noted that PADD 5 includes Alaska and Hawaii.

The economic impacts of the proposed rule are largely determined by behavioral response parameters within the model (i.e., the supply and demand elasticities). For most markets, as summarized in Table 10.1-1, the supply and demand elasticities were either obtained from the professional literature or econometrically estimated. Details on sources and estimation method are provided in Section 10.3 and Appendix 10G. Demand responses in the equipment, engine, and diesel fuel markets are derived internally as a function of changes in output levels in the applications markets (i.e., derived demand specification). Therefore, parameter values are not required for demand elasticities in these markets.

The actual economic impacts of the proposed rule will be determined by the ways in which producers and consumers of the engines, equipment, and fuels affected by the proposal change their behavior in response to the costs incurred in complying with the standards. In the NDEIM, these behaviors are modeled by the demand and supply elasticities. Table 10.1-1 summarizes the sources of the demand and supply elasticities used in the model; more information can be found in section 10.3-5, below. As noted in Table 10.1-1, the supply elasticities for the engine and equipment markets and the demand elasticities for the application markets were estimated using econometric methods. The procedures and results are reported in Appendix 10.1 of this draft RIA. Literature-based estimates were used for the supply elasticities in the application and fuel markets. There are two ways to handle the demand elasticities for the engine, equipment, and fuel markets. The approach in NDEIM internally derives these elasticities based on the specified market linkages, i.e., the demand for engines, equipment, and fuel are modeled as directly related to the supply and demand of goods and services supplied by the final application markets. In other words, the supply of those goods and services determines the demand for equipment and fuel, and the supply of equipment determines the demand for engines. An alternative approach could be used in which the demand elasticities for the equipment, engine, and fuel markets are estimated outside the model.

The estimated supply and demand elasticities used in this analysis for the application markets and the supply elasticity for the diesel fuel market are inelastic or unit elastic. This means that the quantities of goods and services demanded/supplied are expected to be fairly insensitive to price changes (inelastic) or that the quantity demanded/supplied is expected to vary directly with changes in prices. In other words, price changes are not expected to have a large impact on the level of consumption in these application markets. For the agricultural application market, the inelastic supply and demand elasticities reflects the relatively constant demand for food products and the high fixed cost nature of food production. For the construction and manufacturing application markets, the estimated demand and supply elasticities are less inelastic, because consumers have more flexibility to substitute away from construction and manufactured products and producers have more flexibility to adjust production levels. The estimated supply elasticity for the diesel fuel market is also inelastic, because most refineries operate near capacity and are therefore less responsive to fluctuations in market prices. The supply elasticities used in this analysis for the engine and equipment markets, on the other hand, are fairly elastic. This means that quantities supplied in these markets are expected to be very responsive to price changes, that manufacturers are more likely (better able) to change production levels in response to price changes. The demand elasticities for the diesel engine and equipment markets and for the diesel fuel market are not explicitly specified because these demand levels are derived as part of the modeled outcomes for the application markets. It should be noted that these elasticities reflect intermediate run behavioral changes. In the long run, supply and demand are expected to be more elastic since more substitutes may become available.

Table 10.1-1
Summary of Markets in Nonroad Diesel Economic Impact Model (NDEIM)

Model Dimension	**Markets (number)**			
	Diesel Engines (7)	**Diesel Equipment (42)**	**Diesel Fuel (8)**	**Application (3)**
Geographic scope	National	National	Regional by PADDs	National
Product groupings	7 horsepower categories consistent with proposed standard[a]	7 horsepower categories within seven application categories[b,c]	2 diesel fuels by sulfur content (500, 15 ppm) for 4 regional markets[d]	Three broad commodity categories[e]
Market structure	Perfectly competitive	Perfectly competitive	Perfectly competitive	Perfectly competitive
Baseline population	Power Systems Research (PSR) database for 2000 as modified by EPA[f]	Assume one-to-one relationship with engine population	Based on Energy Information Administration (EIA) 2000 fuel consumption data	Value of shipments for 2000 from U.S. Census Bureau
Growth projections	EPA's nonroad model	Based on engine growth	Based on nonroad model and EIA	
Supply elasticity	Econometric estimate (elastic)	Econometric estimate (elastic)	Published econometric estimate (inelastic)	Published econometric estimate (inelastic)
Demand elasticity	Derived demand	Derived demand	Derived demand	Econometric estimate (inelastic)
Regulatory shock	Direct compliance costs cause shift in supply function	Direct compliance costs and higher diesel engine prices cause shift in supply function	Direct compliance costs cause shift in supply function	No direct compliance costs but higher prices for diesel equipment and fuel cause shift in supply function

[a] Horsepower categories are 0-25, 26-50, 51-75, 76-100, 101-175, 176-600, and 601 and greater; the EIA includes more horsepower categories than the standards, allowing more efficient use of the engine compliance cost estimates developed for this proposal.

[b] Engine categories are agricultural (SIC 3523), construction (SIC 3531), pumps and compressors (SIC 3561 and 3563), generator and welder sets (SIC 3548), refrigeration and air conditioning (SIC 3585), general industrial (SIC 3537), and lawn and garden (SIC 3524).

[c] There are seven horsepower/application categories that do not have sales in 2000 and are not included in the model. These are: agricultural equipment >600 hp; gensets & welders > 600 hp; refrigeration & A/C > 71 hp (4 hp categories); and lawn & garden >600 hp. Therefore, the total number of diesel equipment markets is 42 rather than 49.

[d] PADDs 1 and 3 are combined for the purpose of this analysis). It should be noted that PADD 5 includes Alaska and Hawaii.

[e] Application market categories are construction, agriculture, and manufacturing.

[f] See Section 8.1 in Chapter 8 of this draft RIA for an explanation of how the engines were allocated to the seven categories.

Because the elasticity estimates are a key input to the model, a sensitivity analysis for supply and demand elasticity parameters used in the model was also performed as part of this EIA. The results are presented in Appendix 10I. In general, varying the elasticity values across the range of values reported in the literature or using the upper and lower bounds of a 90 percent confidence interval around estimated elasticities has no impact on the magnitude of the total social costs, and only a minimal impact on the distribution of costs across stakeholders. This is because equipment and diesel fuel costs are a relatively small share of total production costs in the construction, agriculture, and manufacturing industries. As a result compliance costs are expected to have little influence on production in these application markets, and the derived demand for equipment, engines and fuel are minimally affected.

With regard to the compliance costs that are used to shock the model, the NDEIM uses the expected increase in variable costs associated with the proposed engine emission standards and the sum of variable and fixed costs associated with the fuel standards. Fixed costs associated with the engine emission standards are not included in the market analysis reported in Table 10.1-2. This is because in an analysis of competitive markets the industry supply curve is based on its marginal cost curve, and fixed costs are not reflected in changes in the marginal cost curve. In addition, fixed costs are primarily R&D costs associated with design and engineering changes, and firms in the affected industries currently allocate funds for these costs. Therefore, fixed costs are not likely to affect the prices of engines or equipment. This assumption is described in greater detail below in Section 10.2.3.3. R&D costs are a long-run concern, and decisions to invest or not invest in R&D are made in the long run. If funds have to be diverted from some other activity into R&D needed to meet the environmental regulations, then these costs represent a component of the social costs of the rule. Therefore, fixed R&D costs are included in the welfare impact estimates reported in Table 10.1-3 as additional costs on producers.

An alternative approach for R&D expenditures can be used, in which these costs are included in intermediate-run decision-making. This alternative assumes that manufacturers will change their behavior based on the R&D required for compliance with the standards. A sensitivity analysis is included in Chapter 10 of the draft RIA for this proposal that reflects this approach.

In addition to the variable and fixed costs described above, there are three additional costs components that are included in the total social cost estimates of the proposed regulation but that are not explicitly included in the NDEIM. These are operating savings (costs), fuel marker costs, and spillover from 15 ppm fuel to higher sulfur fuel.

Operating savings (costs) refers to changes in operating costs that are expected to be realized by users of both existing and new nonroad diesel equipment as a result of the reduced sulfur content of nonroad diesel fuel. These include operating savings (cost reductions) due to fewer oil changes, which accrue to nonroad engines, and marine and locomotive engines, that are already in use as well as new nonroad engines that will comply with the proposed standards. These savings (costs) also include any extra operating costs associated with the new PM emission control technology which may accrue to new engines that use this new technology. These savings (costs) are not included directly in the model because some of the savings accrue to existing engines and because these savings (costs) are not expected to affect consumer decisions with respect to new engines. Instead, they are added into the estimated welfare impacts as additional costs to the application markets, since it is the users of these engines that will see these savings (costs). Nevertheless, a sensitivity analysis was also performed in which these savings (costs) are included as inputs to the NDEIM, where they are modeled as benefits accruing to the application producers. The results of this analysis are presented in Appendix 10.I.

Fuel marker costs refers to costs associated with marking high sulfur diesel fuel in the locomotive, marine, and heating oil markets between 2007 and 2014. Marker costs are not included in the market analysis because locomotive, marine, and heating oil markets are not explicitly modeled in the NDEIM. Similar to the operating savings (costs), marker costs are added into the estimated welfare impacts separately.

The costs of fuel that spills over from the 15 ppm market to higher grade sulfur fuel are also not included in the NDEIM but, instead, are added into the estimated welfare impacts separately. As described in Chapter 7, refiners are expected to produce more 15 ppm fuel than is required for the nonroad diesel fuel market. This excess 15 ppm fuel will be sold into markets that allow fuel with a higher sulfur level (e.g., locomotive, marine diesel, or home heating fuel). Because this spillover fuel will meet the 15 ppm limit, it is necessary to count the costs of sulfur reduction processes against those fuels.

Consistent with the engine and equipment cost discussion in Chapter 6, this EIA does not include any cost savings associated with the proposed equipment transition flexibility program or the proposed nonroad engine ABT program. As a result, the results of this EIA can be viewed as somewhat conservative.

10.1.4 Summary of Economic Analysis

The economic analysis consists of two parts: a market analysis and welfare analysis. The market analysis looks at expected changes in prices and quantities for directly and indirectly affected market commodities as shown in Figure 10.1-1. The welfare analysis looks at economic impacts in terms of annual and present value changes in social costs. For this proposed rule, the social costs are computed as the sum of market surplus offset by operating cost savings. Market surplus is equal to the aggregate change in consumer and producer surplus based on the estimated market impacts associated with the proposed rule. Operating cost savings are associated with the decreased sulfur content of diesel fuel. These include maintenance savings (cost reductions) and changes in fuel efficiency. Increased maintenance costs may also be incurred for some technologies. Operating costs are not included in the market analysis but are instead listed as a separate category in the social cost results tables.

As noted in Chapter 6, engine and equipment costs vary over time because fixed costs are recovered over five to ten year periods while variable costs, despite learning effects that serve to reduce costs on a per unit basis, continue to increase in total at a rate consistent with new sales. Similarly, engine operating costs also vary over time because oil change maintenance savings, PM filter maintenance, and fuel economy effects, all of which are calculated on the basis of gallons of fuel consumed, change over time consistent with the growth in nationwide fuel consumption. Fuel related compliance costs (costs for refining and distributing the proposed fuels) also change over time. These changes are more subtle than the engine costs, however, as the fuel provisions are largely implemented in discrete steps instead of phasing in over time. The total fuel costs do increase as the demand for fuel increases. The variable operating costs are based on the natural gas cost of producing hydrogen and for heating diesel fuel for the new desulfurization equipment, and thus would fluctuate along with the price of natural gas. The distribution costs decrease in 2014 as it would no longer be necessary to use a marker.

Economic impact results for 2013, 2020, and 2030 are presented in this section. The first of these years, 2013, corresponds to the first year in which the standards affect all engines, equipment, and fuels. It should be noted that, as illustrated in Table 8-7-2, aggregate program costs peak in 2014; increases in costs after that year are due increases in the population of engines over time. The other years, 2020 and 2030, correspond to years analyzed in our benefits analysis. Detailed results for all years are included in Appendix 10E for this chapter.

10.1.4.1 What are the Expected Market Impacts of this Proposal?

The market impacts of this rule suggest that the overall economic impact of the proposed emission control program on society is expected be small, on average. According to this analysis, the average price of goods and services produced using equipment and fuel affected by the proposal is expected to increase by about 0.02 percent. The estimated price increases and quantity reductions for engines and equipment vary depending on compliance costs. In general, price increases would be expected to be higher (lower) as a result of a high (low) relative level of compliance costs to market price. The change in price would also be expected to be highest when compliance costs are highest.

This analysis indicates that most of the direct compliance costs for engine, equipment, and fuel producers will be passed through to the application markets in the form of higher prices to the consumers of final construction, agricultural, and manufactured goods and services. This is expected to occur because the demand for nonroad diesel equipment (and hence the derived demand for diesel engines and fuel) is estimated to be relatively price inelastic. The demand for nonroad diesel equipment is inelastic because of the following:

1) Nonroad diesel equipment and fuel expenditures are a relatively small share of total production costs for the products and services that use this equipment and fuel as inputs.
2) There are limited substitutes for nonroad diesel equipment and fuel.

The suppliers to the application markets are thus not expected to respond very much to increases in the price of nonroad diesel equipment and fuel because these factors represent a small share of total production costs. Furthermore, to the extent these increased costs might be significant enough to cause a response, there are few substitutes available to these suppliers. Therefore, the NDEIM predicts a small decrease in demand for diesel equipment and fuel. This would allow engine, equipment and fuel producers to pass through compliance costs in the form of higher prices.

The estimated market impacts for 2013, 2020, and 2030 are presented in Table 10.1-2. The market-level impacts presented in this table represent production-weighted averages of the individual market-level impact estimates generated by the model: the average expected price increase and quantity decrease across all of the units in each of the engine, equipment, fuel, and final application markets. For example, the model includes seven individual engine markets that reflect the different horsepower size categories. The 23 percent price change for engines shown in Table 10.1-2 for 2013 is an average price change across all engine markets weighted by the number of production units. Similarly, equipment impacts presented in Table 10.1-2 are weighted averages of 42 equipment-application markets, such as small (< 25hp) agricultural equipment and large (>600hp) industrial equipment. It should be noted that price increases and quantity decreases for specific types of engines, equipment, application sectors, or diesel fuel markets are likely to be different. But the data in this table provide a broad overview of the expected market impacts that is useful when considering the impacts of the proposal on the economy as a whole. Individual market-level impacts are presented in Appendix 10A through Appendix 10D.

Engine Market Results: Most of the variable costs associated with the proposed rule are passed along in the form of higher prices. The average price increase in 2013 for engines is estimated to be about 23 percent. This percentage is expected to decrease to about 19.5 percent for 2020 and later. This expected price increase varies by engine size because compliance costs are a larger share of total production costs for smaller engines. In 2013, the year of greatest compliance costs overall, the largest expected percent price increase is for engines between 25 and 50 hp: 34 percent or $852; the average price for an engine in this category is about $2,500. However, this price increase is expected to drop to 26 percent, or about $647, for 2016 and later. The smallest expected percent price increase in 2013 is for engines in the greater than 600 hp category. These engines are expected to see price increases of about 3 percent increase in 2013, increasing to about 5.6 percent in 2014 and beyond. The expected price increase for these engines is about $4,211 in 2013, increasing to about $6,950 in 2014 and later, for engines that cost on average about $125,000.

The market impact model predicts that even with these increase in engine prices, total demand is not expected to change very much. The expected average change in quantity is only about 69 engines per year in 2013, out of total sales of more than 500,000 engines. The estimated change in market quantity is small because as compliance costs are passed along the supply chain they become a smaller share of total production costs. In other words, firms that use these engines and equipment will continue to purchase them even at the higher cost because the increase in costs will not have a large impact on their total production costs. Diesel equipment is only one factor of production for their output of construction, agricultural, or manufactured goods. The average decrease in the quantity of all engines produced as a result of the regulation is estimated to be about 0.013 percent. This decrease ranges from 0.010 percent for engines less than 25 hp to 0.016 percent for engines 175 to 600 hp.

Equipment Market Results: Estimated price changes for the equipment markets reflect both the direct costs of the proposed standards on equipment production and the indirect cost through increased engine prices. In 2013, the average price increase for nonroad diesel equipment is estimated to be about 5.2 percent. This percentage is expected to decrease to about 4.5 percent for 2020 and beyond. The range of estimated price increases across equipment types parallels the share of engine costs relative to total equipment price, so the estimated percentage price increase among equipment types also varies. For example, the market price in 2013 for agricultural equipment between 175 and 600 hp is estimated to increase about 1.4 percent, or $1,835 for equipment with an average cost of $130,000. This compares with an estimated engine price increase of about $1,754 for engines of that size. The largest expected price increase in 2013 for equipment is $4,335, or 4.9 percent, for pumps and compressors over 600 hp. This compares with an estimated engine price increase of about $4,211 for engines of that size. The smallest expected price increase in 2013 for equipment is $125, or 3.6 percent, for construction equipment less than 25 hp. This compares with an estimated engine price increase of about $124 for engines of that size. The price changes for the equipment are less than that for engines because the engine is only one input in the production of equipment.

The output reduction for nonroad diesel equipment is estimated to be very small and to average about 0.014 percent for all years. This decrease ranges from 0.005 percent for general manufacturing equipment to 0.019 percent for construction equipment. The largest expected decrease in quantity in 2013 is 13 units of construction equipment per year for construction equipment between 100 and 175 hp, out of about 62,800 units. The smallest expected decrease in quantity in 2013 is less than one unit per year in all hp categories of pumps and compressors.

Table 10.1-2
Summary of Market Impacts ($2001)

Market	Engineering Cost	Change in Price		Change in Quantity	
	Per Unit	Absolute ($million)	Percent	Absolute	Percent
2013					
Engines	$1,087	$840	22.9	–69[a]	–0.013
Equipment	$1,021	$1,017	5.2	–118	–0.014
Application Markets[b]			0.02		–0.010
No. 2 Distillate Nonroad	$0.039	$0.038	4.1	–1.38[c]	–0.013
2020					
Engines	$1,028	$779	19.5	–79[a]	–0.013
Equipment	$1,018	$1,013	4.4	–135	–0.014
Application Markets[b]			0.02		–0.010
No. 2 Distillate Nonroad	$0.039	$0.039	4.1	–1.58[c]	–0.014
2030					
Engines	$1,027	$768	19.4	–92[a]	–0.013
Equipment	$1,004	$999	4.5	–156	–0.014
Application Markets[b]			0.02		–0.010
No. 2 Distillate Nonroad	$0.039	$0.039	4.1	–1.84[c]	–0.014

[a] The absolute change in the quantity of engines represents only engines sold on the market. Reductions in engines consumed internally by integrated engine/equipment manufacturers are not reflected in this number but are captured in the cost analysis. For this reason, the absolute change in the number of engines and equipment does not match.
[b] The model uses normalized commodities in the application markets because of the great heterogeneity of products. Thus, only percentage changes are presented.
[c] Units are in million of gallons.

Application Market Results: The estimated price increase associated with the proposed standards in all three of the application markets is very small and averages about 0.02 percent for all years. In other words, on average, the prices of goods and services produced using the engines, equipment, and fuel affected by this proposal are expected to increase only negligibly. This is because in all of the application markets the compliance costs passed on through price increases represent a very small share of total production costs. For example, the construction industry realizes an increase in production costs of approximately $468 million in 2013 because of the price increases for diesel equipment and fuel. However, this represents only 0.03 percent of the $1,392 billion value of shipments in the construction industry in 2001. The estimated average commodity price increase in 2013 ranges from 0.06 percent in the agricultural application market to about 0.01 percent in the manufacturing application market. The percentage change in output is also estimated to be very small and averages about 0.01 percent. This reduction ranges from less than a 0.01 percent decrease in manufacturing to about a 0.02 percent decrease in construction. Note that these estimated price increases and quantity decreases are average for these sectors and may vary for specific subsectors. Also, note that absolute changes in price and quantity are not provided for the application markets in Table 10.1-2 because normalized commodity values are used in the market model. Because of the great heterogeneity of manufactured or agriculture products, a normalized commodity ($1 unit) is used in the application markets. This has no impact on the estimated percentage change impacts but makes interpretation of the absolute changes less informative.

Fuel Markets Results: The estimated average price increase across all nonroad diesel fuel is about 4 percent for all years. For 15 ppm fuel, the estimated price increase for 2013 ranges from 3.2 percent in the East Coast region (PADD 1&3) to 9.3 percent in the mountain region (PADD 4). The average national output decrease for all fuel is estimated to be about 0.01 percent for all years, and is relatively constant across all four regional fuel markets.

10.1.4.2 What are the Expected Social Costs of this Proposal?

Social costs include the changes in market surplus estimated by the NDEIM and changes in operating costs and marker costs associated with the regulation. Table 10.1-3 shows the time series of engineering compliance costs and social cost estimates for 2007 through 2030. As shown, these estimates are of similar magnitude for each year of the analysis. However, the distribution of costs across the affected stakeholders is very different. This is highlighted by the comparison of Figure 10.1-3a and Figure 10.1-3b, which show the way in which the estimated engineering compliance costs and the estimated social costs are distributed across stakeholders, for 2013. Figure 10.1-3a shows that the direct compliance costs are borne relatively evenly across engine, equipment, and fuel producers, with each bearing about one-third of the costs. In contrast, as shown in Figure 10.1-3b, most of the social costs are borne by producers and consumers in the application markets (about 89 percent when the operating savings (costs) are not considered) due to the increased prices for diesel engines, equipment, and fuel. Engine producers are able to pass on 94 percent their compliance costs through higher prices. The remaining 6 percent are primarily fixed R&D costs that are internalized by engine manufacturers and not passed into the market. Equipment manufacturers retain a slightly higher share of compliance costs because they have greater fixed costs. Diesel fuel refiners pass over 98 percent of their compliance costs on to the application producers and consumers because, as discussed in Chapter 6, refiners pass both fixed and variable costs into the market.

Table 10.1-3
National Engineering Compliance Costs and
Social Costs Estimates for the Proposed Rule (2004 - 2030)
($2001; $Million)

Year	Engineering Compliance Costs	Total Social Costs
2004	$0.00	$0.00
2005	$0.00	$0.00
2006	$0.00	$0.00
2007	$39.61	$39.61
2008	$130.41	$130.40
2009	$132.25	$132.25
2010	$262.02	$262.01
2011	$641.12	$641.07
2012	$1,010.37	$1,010.27
2013	$1,202.52	$1,202.40
2014	$1,329.14	$1,329.01
2015	$1,260.74	$1,260.62
2016	$1,298.40	$1,298.27
2017	$1,318.75	$1,318.62
2018	$1,325.02	$1,324.89
2019	$1,339.30	$1,339.16
2020	$1,366.79	$1,366.66
2021	$1,351.08	$1,350.94
2022	$1,349.58	$1,349.44
2023	$1,365.53	$1,365.38
2024	$1,371.60	$1,371.45
2025	$1,395.98	$1,395.83
2026	$1,419.79	$1,419.64
2027	$1,442.91	$1,442.76
2028	$1,465.41	$1,465.26
2029	$1,487.68	$1,487.53
2030	$1,509.77	$1,509.61
NPV at 3%	$16,524.29	$16,522.66
NPV at 7%	$9,894.02	$9,893.06

Figure 10.1-2 shows the time series of total social costs from 2007 through 2030. Social costs increase rapidly between 2007 and 2013 as engine, equipment and fuel costs are phased into the regulation. Estimated net annual social costs (including operating savings (cost) and marker costs) in 2013 are about $1,202 million. After 2013, per unit compliance costs decrease as fixed costs are depreciated. However, due to growth in engine and equipment sales and related fuel consumption, net social costs are expected continue to increase, but at a slower rate, from 2014 to 2030. The estimated net present value of social costs over the time period 2004 through 2030 based on a social discount rate of 3 percent is reported in Table 10.1-3 and is about $16.5 billion. The present value over this same period based on a social discount rate of 7 percent is about $9.9 billion.

Figure 10.1-2
Total Social Costs (2004-2030)

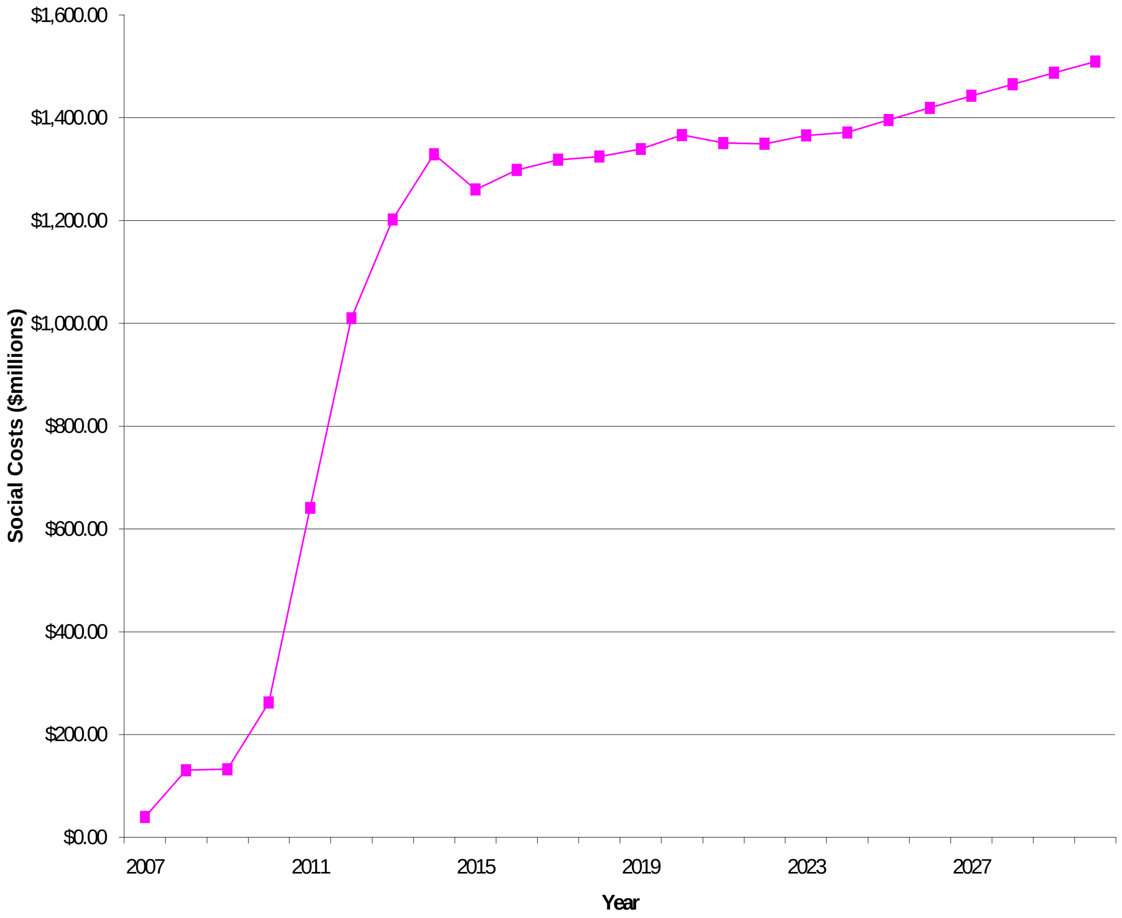
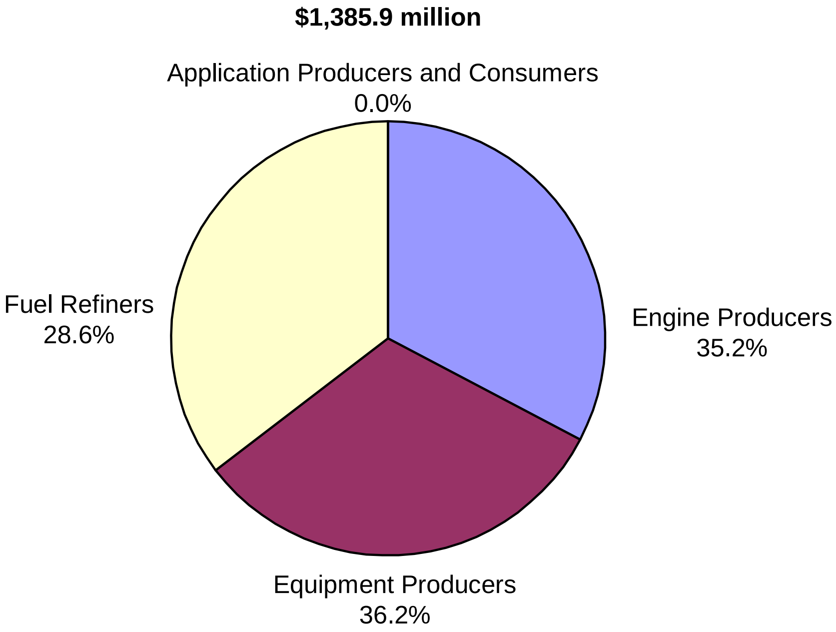
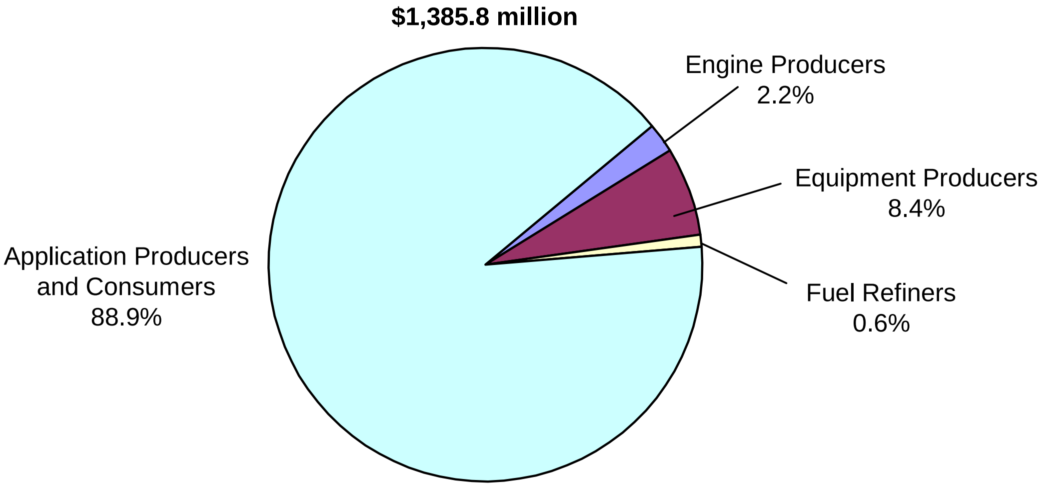


Figure 10.1-3
Comparison of the Distribution of Engineering Compliance
and Social Cost Estimates by Industry Segment (2013)



a) Engineering Cost Distribution[a]



b) Social Cost Distribution[a]

[a] Costs do not include operating cost savings, nonroad spillover, or marker costs, which represent negative 183.4 million in costs (i.e., benefits).

Estimated social costs are disaggregated by market in Table 10.1-4, for 2013, 2020, and 2030. A more detailed time series from 2007 to 2030 provided is in Appendix 10.E. The data in Table 10.1-4 shows that in 2013, social costs are expected to be about $1,202.4 million ($2001). About 82 percent of the total social costs is expected to be borne by producers and consumers in the application markets, indicating that the majority of the costs are expected to be passed on in the form of higher prices. When these estimated impacts are broken down, about 58 percent of the social costs are expected to be borne by consumers in the application markets and about 42 percent are expected to be borne by producers in the application markets. Equipment manufacturers are expected to bear about 10 percent of the total social costs. Engine manufacturers and diesel fuel refineries are expected to bear 2.5 percent and 0.5 percent, respectively. The remaining 5.0 percent is accounted for by fuel marker costs and the additional costs of 15 ppm fuel being sold in to markets such as marine diesel, locomotive, and home heating fuel that do not require it.

In 2030, the total social costs are projected to be about $1,509.6 million ($2001). The increase is due to the projected annual growth in the engine and equipment populations. As in earlier years, producers and consumers in the application markets are expected to bear the large majority of the costs, approximately 94 percent. This is consistent with economic theory, which states that, in the long run, all costs are passed on to the consumers of goods and services.

Table 10.1-4
Summary of Social Costs Estimates Associated with Primary Program: 2013, 2020, and 2030 ($million)[a,b]

	Maximum Cost Year (2013)				Year 2020				Final Year (2030)			
	Market Surplus ($$10^6$)	Operating Savings ($$10^6$)	Total	Percent	Market Surplus ($$10^6$)	Operating Savings ($$10^6$)	Total	Percent	Market Surplus ($$10^6$)	Operating Savings ($$10^6$)	Total	Percent
Engine Producers Total	$30.2		$30.2	2.5%	$0.1		$0.1	0.01%	$0.1		$0.1	0.0%
Equipment Producers Total	$116.1		$116.1	9.7%	$102.6		$102.6	7.5%	$5.3		$5.3	0.3%
Construction Equipment	$53.0		$53.0		$48.2		$48.2		$3.8		$3.8	
Agricultural Equipment	$39.9		$39.9		$33.2		$33.2		$1.3		$1.3	
Industrial Equipment	$23.2		$23.2		$21.2		$21.2		$0.2		$0.2	
Application Producers & Consumers Total	$1,231.8	($241.9)	$989.8	82.3%	$1,386.5	($190.1)	$1,196.3	87.5%	$1,598.9	($174.5)	$1,424.5	94.4%
Total Producer	*$515.7*				*$583.4*				*$672.9*			
Total Consumer	*$716.1*				*$803.1*				*$926.0*			
Construction	$468.3	($77.9)	$390.4		$550.4	($61.2)	$489.3		$635.7	($56.1)	$579.5	
Agriculture	$348.7	($44.7)	$304.0		$339.2	($35.2)	$364.0		$416.5	($32.3)	$429.2	
Manufacturing	$414.8	($119.3)	$295.5		$436.8	($93.8)	$343.0		$501.8	($86.0)	$415.7	
Fuel Producers Total	$7.8		$7.8	0.6%	$9.0		$9.0	0.7%	$10.5		$10.5	0.7%
PADD I&III	$3.6		$3.6		$4.1		$4.1		$4.8		$4.8	
PADD II	$2.9		$2.9		$3.3		$3.3		$3.9		$3.9	
PADD IV	$0.8		$0.8		$0.9		$0.9		$1.0		$1.0	
PADD V	$0.5		$0.5		$0.6		$0.6		$0.8		$0.8	
Nonroad Spillover		$51.2		$4.3		$58.6		$4.3		$69.2		4.6%
Marker Costs		$7.3		0.6%		–		0.0%		–		0.0%
Total	$1,385.8	($183.4)	$1,202.4	100%	$1,498.2	($131.5)	$1,366.7	100%	$1,614.9	($105.3)	$1,509.6	100%

[a] Figures are in 2001 dollars.
[b] Operating savings are shown as negative costs.

Table 10.1-5
Summary of Social Costs Estimates Associated with Primary Program:
NPV, 3%, 2004-2030 ($million)[a,b]

	Market Surplus ($$10^6$)	Fuel Maintenance ($$10^6$)	Total	Percent
Engine Producers Total	$190.0		$190.0	1.1%
Equipment Producers Total	$927.4		$927.4	5.6%
Construction Equipment	$433.6		$433.6	
Agricultural Equipment	$306.7		$306.7	
Industrial Equipment	$187.1		$187.1	
Application Producers & Consumers Total	$17,744.2	($3,402.4)	$14,341.8	86.8%
Total Producer	*$7,450.7*			
Total Consumer	*$10,293.5*			
Construction	$6,923.5	($1,094.9)	$5,828.6	
Agriculture	$5,050.4	($629.3)	$4,421.1	
Manufacturing	$5,770.3	($1,678.1)	$4,092.2	
Fuel Producers Total	$113.9		$113.9	0.7%
PADD I&III	$52.3		$52.3	
PADD II	$41.9		$41.9	
PADD IV	$11.5		$11.5	
PADD V	$8.1		$8.1	
Nonroad Spillover		$886.5		5.4%
Marker Costs		$63.0		0.4%
Total	$18,975.5	($2,452.8)	$16,522.7	100%

[a] Figures are in 2001 dollars.
[b] Operating savings are shown as negative costs.

10.2 Economic Methodology

Economic impact analysis uses a combination of theory and econometric modeling to evaluate potential behavior changes associated with a new regulatory program. As noted above, the goal is to estimate the impact of the regulatory program on producers and consumers. This is done by creating a mathematical model based on economic theory and populating the model using publically available price and quantity data. A key factor in this type of analysis is estimating the responsiveness of the quantity of engines, equipment, and fuels demanded by consumers or supplied by producers to a change in the price of that product. This relationship is called the elasticity of demand or supply. This section discusses the economic theory underlying the modeling for this EIA and several key issues that affect the way the model was developed.

10.2.1 Behavioral Economic Models

Models incorporating different levels of economic decision making can generally be categorized as *with*-behavior responses or *without*-behavior responses (engineering cost analysis). Engineering cost analysis is an example of the latter and provides detailed estimates of the cost of a regulation based on the projected number of affected units and engineering estimates of the annualized costs.

The behavioral approach builds on the engineering cost analysis and incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. Owners of affected plants are economic agents that can make adjustments, such as changing production rates or altering input mixes, that will generally affect the market environment in which they operate. As producers change their production levels in response to a regulation, consumers are typically faced with changes in prices that cause them to alter the quantity that they are willing to purchase. These changes in price and output from the market-level impacts are used to estimate the distribution of social costs between consumers and producers.

Generally, the behavioral approach and engineering cost approach yield approximately the same total cost impact. However, the advantage of the behavioral approach is that it illustrates how the costs flow through the economic system and identifies which stakeholders, producers, and consumers are most affected.

10.2.2 Conceptual Economic Approach

This EIA models basic economic relationships between supply and demand to estimate behavioral changes expected to occur as a result of the proposed regulation. An overview of the basic economic theory used to develop the model to estimate the potential effect of the proposed program on market outcomes is presented in this section. Following the *OAQPS Economic Analysis Resource Document* (EPA, 1999), standard concepts in microeconomics are used to model the supply of affected products and the impacts of the regulations on production costs and the operating decisions.

10.2.2.1 Types of Models: Partial vs. General Equilibrium Modeling Approaches

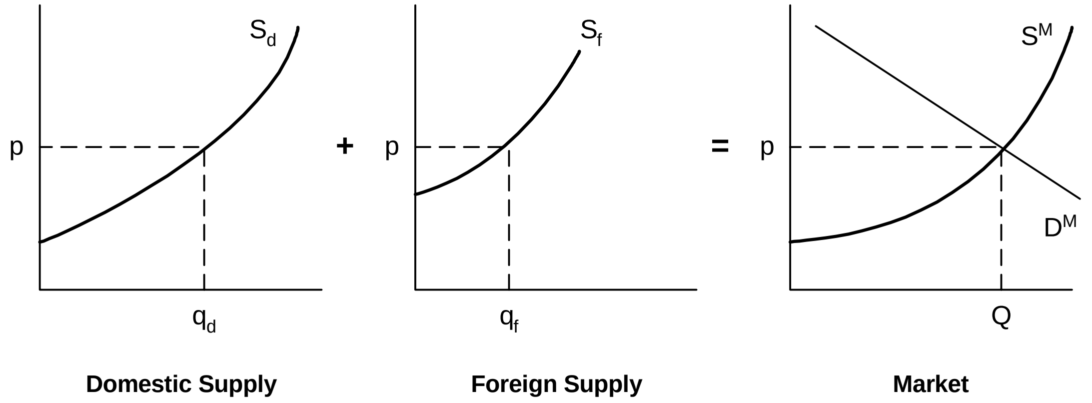
In the broadest sense, all markets are directly or indirectly linked in the economy; thus, the proposed regulation will affect all commodities and markets to some extent. The appropriate level of market interactions to be included in an EIA is determined by the number of industries directly affected by the requirements and the ability of affected firms to pass along the regulatory costs in the form of higher prices. Alternative approaches for modeling interactions between economic sectors can generally be divided into three groups:

- *Partial equilibrium model*—Individual markets are modeled in isolation. The only factor affecting the market is the cost of the regulation on facilities in the industry being modeled; there are no interaction effects with other markets.
- *General equilibrium model*—All sectors of the economy are modeled together, incorporating interaction effects between all sectors included in the model. General equilibrium models operationalize neoclassical microeconomic theory by modeling not only the direct effects of control costs but also potential input substitution effects, changes in production levels associated with changes in market prices across all sectors, and the associated changes in welfare economy-wide. A disadvantage of general equilibrium modeling is that substantial time and resources are required to develop a new model or tailor an existing model for analyzing regulatory alternatives.
- *Multimarket model*—A subset of related markets is modeled together, with sector linkages, and hence selected interaction effects, explicitly specified. This approach represents an intermediate step between a simple, single-market partial equilibrium approach and a full general equilibrium approach. This technique has most recently been referred to in the literature as “partial equilibrium analysis of multiple markets” (Berck and Hoffmann, 2002).

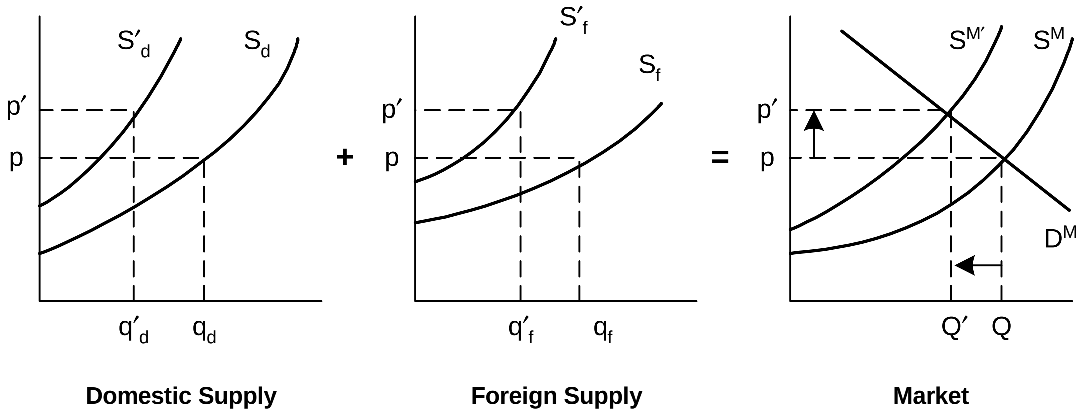
This analysis uses a behavioral multimarket framework because the benefits of increasing the dimensions of the model outweigh the cost associated with additional model detail. As Bingham and Fox (1999) note, this increased scope provides “a richer story” of the expected distribution of economic welfare changes across producers and consumers. Therefore, the NDEIM developed for this analysis consists of a spreadsheet model that links a series of standard partial equilibrium models by specifying the interactions between the supply and demand for products. Changes in prices and quantities are then solved across all markets *simultaneously*. The following markets were included in the model; their linkages are illustrated in Figure 10.2-1 and they are described in detail in Section 10.3.3 below:

- seven diesel engine markets categorized by engine size;
- 42 equipment markets, including construction, agriculture, refrigeration, lawn and garden, pumps and compressors, generators and welder sets, and general industrial equipment types—with five to seven horsepower size categories for each equipment type;
- eight fuel markets, four regions (PADDs) each with two nonroad diesel fuel markets (500 ppm and 15 ppm); and
- three application markets (construction, agriculture, and manufacturing).

Figure 10.2-1
Market Equilibrium without and with Regulation



a) Baseline Equilibrium



b) With-Regulation Equilibrium

10.2.2.2 Market Equilibrium in a Single Commodity Market

A graphical representation of a general economic competitive model of price formation, as shown in Figure 10.2-1(a), posits that market prices and quantities are determined by the intersection of the market supply and market demand curves. Under the baseline scenario, a market price and quantity (p,Q) are determined by the intersection of the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M). The market supply curve reflects the sum of the domestic (S_d) and import (S_f) supply curves.

With the regulation, the costs of production increase for suppliers. The imposition of these regulatory control costs is represented as an upward shift in the supply curve for domestic and import supply, by the estimated compliance costs. As a result of the upward shift in the supply curve, the market supply curve will also shift upward as shown in Figure 10.2-1(b) to reflect the increased costs of production.

At baseline without the proposed rule, the industry produces total output, Q, at price, p, with domestic producers supplying the amount q_d and imports accounting for Q minus q_d, or q_f. With the regulation, the market price increases from p to p′, and market output (as determined from the market demand curve) declines from Q to Q′. This reduction in market output is the net result of reductions in domestic and import supply.

10.2.2.3 Incorporating Multimarket Interactions

The above description is typical of the expected market effects for a single product market (e.g., diesel engine manufacturers) considered in isolation. However, the modeling problem for this EIA is more complicated because of the need to investigate affected equipment manufacturers and fuel producers as well as engine manufacturers.

For example, the proposed Tier 4 standards will affect equipment producers in two ways. First, these producers are affected by higher input costs (increases in the price of diesel engines) associated with the rule. Second, the standards will also impose additional production costs on equipment producers associated with equipment changes necessary to accommodate changes in engine design.

The demand for diesel engines is directly linked to the production of diesel equipment. A single engine is typically used in each piece of equipment, and there are no substitutes (i.e., to make diesel equipment one needs a diesel engine). For this reason, it is reasonable to assume that the input-output relationship between the diesel engines and the equipment is strictly fixed and that the demand for engines varies directly with the demand for equipment.[A]

The demand for diesel equipment is directly linked to the production of final goods and services that use diesel equipment. For example, the demand for agricultural equipment depends on the final demand for agricultural products and the total price of supplying these products. Thus, any change in the price of agricultural equipment will shift the agriculture supply curve, leading to a decrease in agricultural production and hence decreased consumption of agricultural equipment. Assuming a fixed input-output relationship, the percentage change in agricultural production will equal the percentage change in agricultural equipment production.

These relationships link the demand for engines and equipment directly to the level of production of goods and services in the application markets. A demand curve specified in terms of its downstream consumption is referred to as a derived demand curve. Figure 10.2-2 graphically illustrates how a derived demand curve is identified. Consider an event in the

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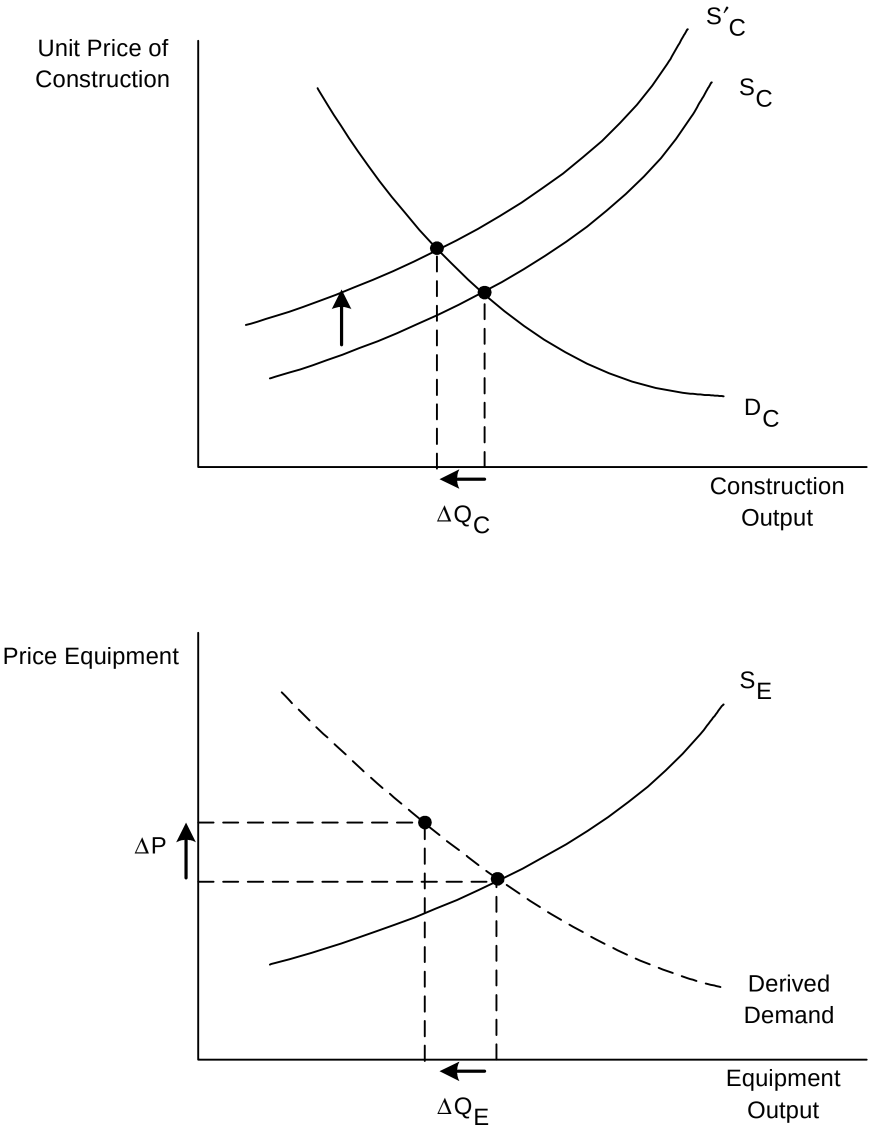
[A] This one-to-one relationship holds for engines sold on the market and for engines consumed internally by integrated engine/equipment manufacturers.

construction equipment market that causes the price of equipment to increase by ΔP (such as an increase in the price of engines). This increase in the price of equipment will cause the supply curve in the construction market to shift up, leading to a decreased quantity of construction activity (ΔQ_C). The change in construction activity leads to a decrease in the demand for construction equipment (ΔQ_E). The new point ($Q_E - \Delta Q_E$, $P - \Delta P$) traces out the derived demand curve. Note that the supply and demand curves in the construction applications market are needed to identify the derived demand in the construction equipment market. The construction application market supply and demand curves are functional form and elasticity parameters described in Appendix10F.

Figure 10.2-2
Derived Demand for Construction Equipment



ΔPrice Equipment ⟶ Upward Shift Construction Supply Curve ⟶ ΔQ_C ⟶ ΔQ_E

Each point on the derived demand curve equals the construction industry's willingness to pay for the corresponding marginal input. This is typically referred to as the input's net value of marginal product (VMP), which is equal to the price of the output (P_x) times the input's marginal physical product (MPP). MPP is the incremental construction output attributable to a change in equipment inputs:

$$\text{Value Marginal Product (VMP)} = P_x * \text{MPP}.$$

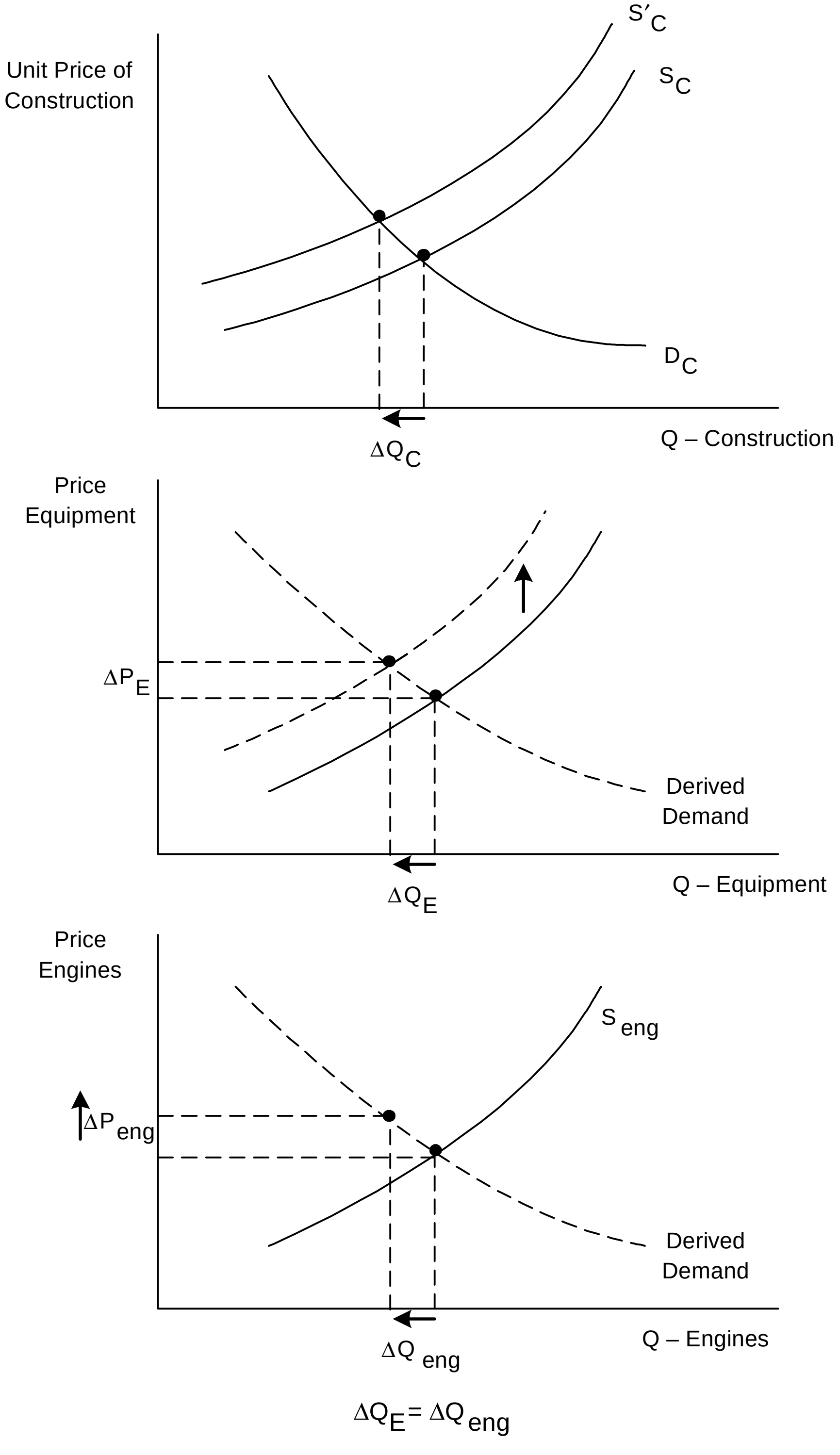
An increase in regulatory costs (c) associated with equipment will lower the VMP of all inputs, leading to a decrease in the net marginal product:

$$\text{Net Value Marginal Product} = (P_x - c) * \text{MPP}.$$

This decrease in the VMP of equipment, as price increases, is what leads the downward-sloping derived demand curve in the equipment market.

Similarly, derived demand curves are developed for the engine markets that supply the equipment markets. As shown in Figure 10.2-3, the increased price of engines resulting from regulatory costs shifts the supply curve for engines and leads to a shift in the supply curve for equipment. The resulting increased price of equipment leads to a shift in the supply curve for the construction industry, decreasing construction output. The decrease in construction output flows back through the equipment market, resulting in decreased demand for engines (ΔQeng).

Figure 10.2-3
Derived Demand for Engines



10.2.3 Key Modeling Elements

In addition to specifying the type of model used and the relationships between the markets, it is also necessary to specify several other key model characteristics. These characteristics include the degree of competition in each market, the time horizon of the analysis, and how fixed costs affect firms' production decisions. The specification of the industry/market characteristics and how regulatory costs are introduced into the model has an impact on the size and interpretation of the estimated economic impacts. These modeling issues are discussed below.

10.2.3.1 Perfect vs. Imperfect Competition

For all markets that are modeled, the analyst must characterize the degree of competition within each market. The discussion generally focuses on perfect competition (price-taking behavior) versus imperfect competition (the lack of price-taking behavior). The central issue is whether individual firms have sufficient market power to influence the market price.

Under imperfect (such as monopolistic) competition, firms produce products that have unique attributes that differentiate them from competitors' products. This allows them to limit supply, which in turn increases the market price, given the traditional downward-sloping demand curve. Decreasing the quantity produced increases the monopolist's profits but decreases total social surplus because a less than optimal amount of the product is being consumed. In the monopolistic equilibrium, the value society (consumers) places on the marginal product, the market price, exceeds the marginal cost to society (producers) of producing the last unit. Thus, social welfare would be increased by inducing the monopolist to increase production.

Social cost estimates associated with a proposed regulation are larger with monopolistic market structures because the regulation exacerbates an already social inefficiency of too little output from a social perspective. The Office of Management and Budget (OMB) explicitly mentions the need to consider these market power-related welfare costs in evaluating regulations under Executive Order 12866 (OMB, 1996).

However, as discussed in the industry profiles in Chapter 1, most of the diesel engine and equipment markets have significant levels of domestic and international competition. Even in markets where a few firms dominate the market, there is significant excess capacity enabling competitors to quickly respond to changes in price. For this reason, for the nonroad diesel rule analysis, it is assumed that within each modeled engine and equipment market the commodities of interest are similar enough to be considered homogeneous (e.g., perfectly substitutable) and that the number of buyers and sellers is large enough so that no individual buyer or seller has market power or influence on market prices (i.e., perfect competition). As a result of these conditions, producers and consumers take the market price as given when making their production and consumption choices.

With regard to the fuel market, the Federal Trade Commission (FTC) has developed an approach to ensure competitiveness in this sector. The FTC reviews oil company mergers and frequently requires divestiture of refineries, terminals, and gas stations to maintain a minimum level of competition. Therefore, it is reasonable to assume a competitive structure for this market. At the same time, however, there are several ways in which refiners may pass along their fuel compliance costs. This analysis explores three approaches. The primary modeling scenario is the average cost scenario, according to which the change in market price is driven by the average total (variable + fixed) regional cost of the regulation. The two other approaches are modeled in a sensitivity analysis and reflect the case in which the highest-cost producer sets the market price in a region. The first of these is the maximum variable cost scenario, according to which the market price is drive by the maximum variable regional cost of the regulation. The second is the maximum total (fixed + variable) regional cost of the regulation. The results of the sensitivity analyses for these two fuel scenarios are contained in Appendix 10I.

10.2.3.2 Short- vs. Long-Run Models

In developing the multimarket partial equilibrium model, the choices available to producers must be considered. For example, are producers able to increase their factors of production (e.g., increase production capacity) or alter their production mix (e.g., substitution between materials, labor, and capital)? These modeling issues are largely dependent on the time horizon for which the analysis is performed. Three benchmark time horizons are discussed below: the very short run, the long run, and the intermediate run. This discussion relies in large part on the material contained in the *OAQPS Economic Analysis Resource Guide* (U.S. EPA, 1999).

In the very short run, all factors of production are assumed to be fixed, leaving the directly affected entity with no means to respond to increased costs associated with the regulation. Within a very short time horizon, regulated producers are constrained in their ability to adjust inputs or outputs due to contractual, institutional, or other factors and can be represented by a vertical supply curve as shown in Figure 10.2-4. In essence, this is equivalent to the nonbehavioral model described earlier. Neither the price nor quantity change and the manufacturer’s compliance costs become fixed or sunk costs. Under this time horizon, the impacts of the regulation fall entirely on the regulated entity. Producers incur the entire regulatory burden as a one-to-one reduction in their profit. This is referred to as the “full-cost absorption” scenario and is equivalent to the engineering cost estimates. While there is no hard and fast rule for determining what length of time constitutes the very short run, it would be inappropriate to use this time horizon for this analysis because it assumes economic entities have no flexibility to adjust factors of production.

In the long run, all factors of production are variable, and producers can be expected to adjust production plans in response to cost changes imposed by a regulation. Figure 10.2-5 illustrates a typical, if somewhat simplified, long-run industry supply function. The function is horizontal, indicating that the marginal and average costs of production are constant with respect to output.[B] This horizontal slope reflects the fact that, under long-run constant returns to scale, technology and input prices ultimately determine the market price, not the level of output in the market.

[B] The constancy of marginal costs reflects an underlying assumption of constant returns to scale of production, which may or may not apply in all cases.

Figure 10.2-4
Full-Cost Absorption of Regulatory Costs

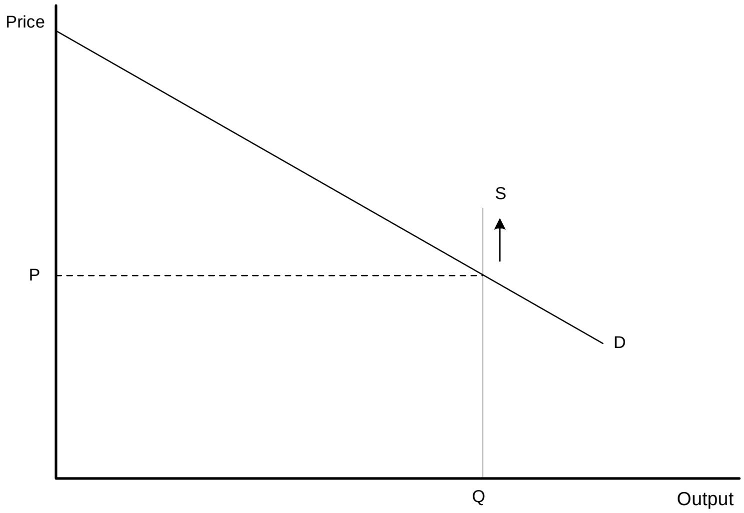


Figure 10.2-5
Full-Cost Pass-Through of Regulatory Costs

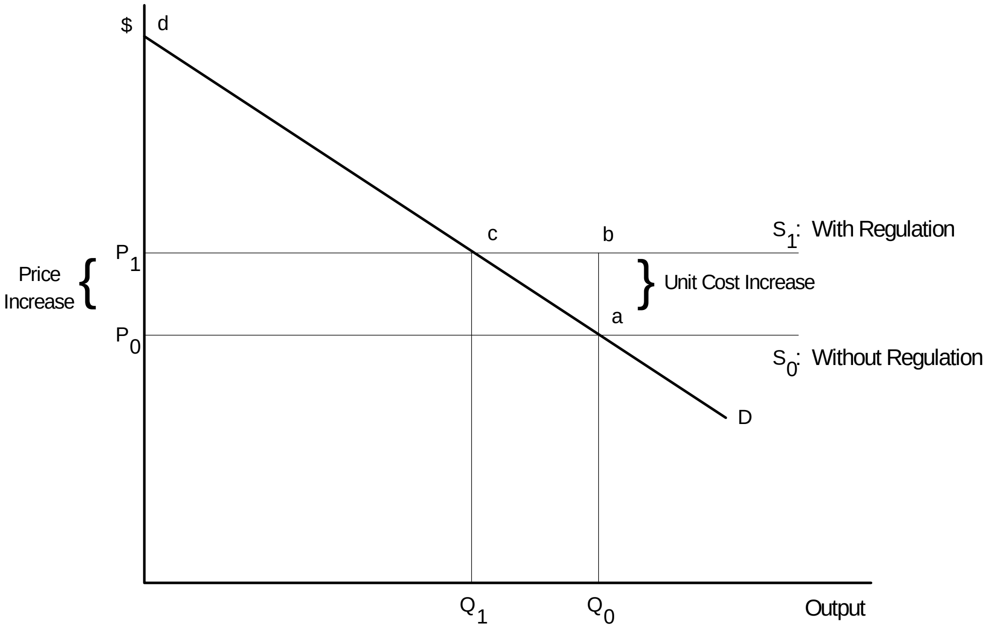
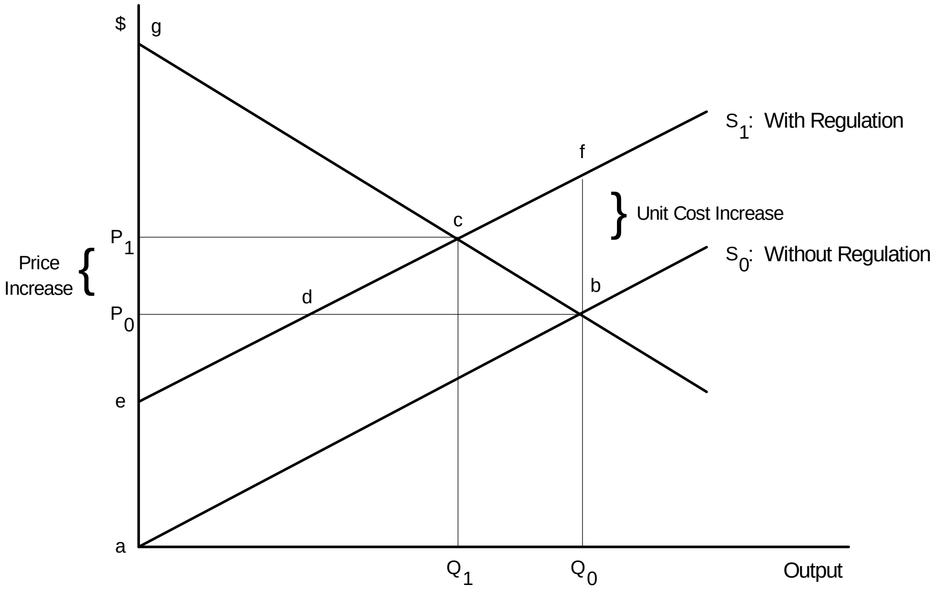


Figure 10.2-6
Partial Cost Pass-Through of Regulatory Costs



Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward parallel shift in the market supply curve represents the regulation’s effect on production costs. The shift causes the market price to increase by the full amount of the per-unit control cost (i.e., from P_0 to P_1). With the quantity demanded sensitive to price, the increase in market price leads to a reduction in output in the new with-regulation equilibrium (i.e., Q_0 to Q_1). As a result, consumers incur the entire regulatory burden as represented by the loss in consumer surplus (i.e., the area P_0 ac P_1). In the nomenclature of EIAs, this long-run scenario is typically referred to as “full-cost pass-through,” and is illustrated in Figure 10.2-5.

Taken together, impacts modeled under the long-run/full-cost-pass-through scenario reveal an important point: under fairly general economic conditions, a regulation’s impact on producers is transitory. Ultimately, the costs are passed on to consumers in the form of higher prices. However, this does not mean that the impacts of a regulation will have no impact on producers of goods and services affected by a regulation. For example, the long run may cover the time taken to retire all of today’s capital vintage, which could take decades. Therefore, transitory impacts could be protracted and could dominate long-run impacts in terms of present value. In addition, to evaluate impacts on current producers, the long-run is approach is not appropriate. Consequently an time horizon that falls between the very short-run/full-cost-absorption case and the long-run/full-cost-pass-through case is most appropriate for this EIA.

The intermediate run can best be defined by what it is not. It is not the very short run and it is not the long run. In the intermediate run, some factors are fixed; some are variable.[C] The existence of fixed production factors generally leads to diminishing returns to those fixed factors. This typically manifests itself in the form of a marginal cost (supply) function that rises with the output rate, as shown in Figure 10.2-6.

Again, the regulation causes an upward shift in the supply function. The lack of resource mobility may cause producers to suffer profit (producer surplus) losses in the face of regulation; however, producers are able to pass through some of the associated costs to consumers, to the extent the market will allow. As shown, in this case, the market-clearing process generates an increase in price (from P_0 to P_1) that is less than the per-unit increase in costs (fb), so that the regulatory burden is shared by producers (net reduction in profits) and consumers (rise in price). In other words there is a loss of both producer and consumer surplus.

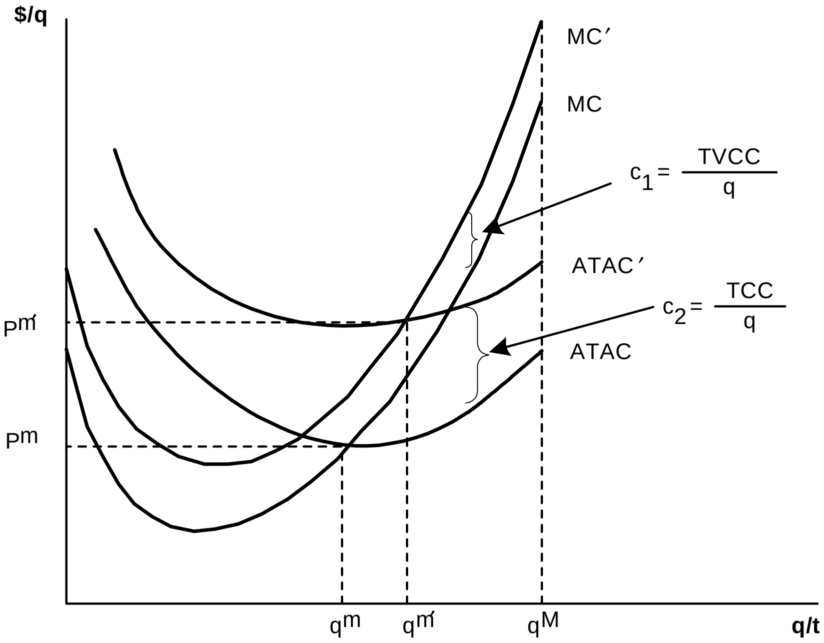
10.2.3.3 Variable vs. Fixed Regulatory Costs

Related to short-run versus long-run modeling issues is the question of how fixed and variable cost increases affect market prices and quantities. The engineering estimates of fixed R&D and capital costs and variable material and operating and maintenance (O&M) costs provide an initial measure of total annual compliance costs without accounting for behavioral responses. The starting point for assessing the market impacts of a regulatory action is to incorporate the regulatory compliance costs into the production decision of the firm.

In general, shifting the supply curve by the total cost per unit implies that both capital and operating costs vary with output levels. At least in the case of capital, this raises some questions. In the long run, all inputs (and their costs) can be expected to vary with output. But a short(er)-run analysis typically holds some capital factors fixed. For instance, to the extent that a market supply function is tied to existing facilities, there is an element of fixed capital (or one-time R&D). As indicated above, the current market supply function might reflect these fixed factors with an upward slope. As shown in Figure 10.2-7, the MC curve will only be affected, or shift upwards, by the per-unit variable compliance costs, while the ATAC curve will shift up by the per-unit total compliance costs (c_2). Thus, the variable costs will directly affect the production decision (optimal output rate), and the fixed costs will affect the closure decision by establishing a new higher reservation price for the firm (i.e., $P^{m'}$). In other words, the fixed costs are important in determining whether the firm will stay in this line of business (i.e., produce anything at all), and the variable costs determine the level (quantity) of production.

[C] As a semantical matter, the situation where some factors are variable and some are fixed is often referred to as the “short run” in economics, but the term “intermediate run” is used here to avoid any confusion with the term “very short run.”

Figure 10.2-7
Modeling Fixed Costs



(a) Upward-sloping supply function

In the EIA for this rule, it is assumed that only the variable cost influences the firm's production decision level and that the fixed costs are absorbed by the firm. Fixed costs associated with the engine emission standards are not included in the market analysis. This is because in an analysis of competitive markets the industry supply curve is based on its marginal cost curve, and fixed costs are not reflected in changes in the marginal cost curve. In addition, fixed costs are primarily R&D costs associated with design and engineering changes, and firms in the affected industries currently allocate funds for these costs (see below). These costs are still a cost to society because they displace other R&D activities that may improve the quality or performance of engines and equipment. However, in this example, the fixed costs would not influence the market price or quantity in the intermediate run. Therefore, fixed costs are not likely to affect the prices of engines or equipment.

R&D costs are a long-run concern, and decisions to invest or not invest in R&D are made in the long run. If funds have to be diverted from some other activity into R&D needed to meet the environmental regulations, then these costs represent a component of the social costs of the rule. Therefore, fixed R&D costs are included in the welfare impact estimates reported in Table 10.1-4 as unavoidable costs that reduce producer surplus. In other words, engine manufacturers budget for research and development programs and include these charges in their long-run strategies. In the absence of new standards, these resources would be focused on design changes to increase customer satisfaction. Engine manufacturers are expected to redirect these resources toward compliance with the standards, instead of adding additional resources to research and development programs.

Operationally, the model used in this EIA shifts the diesel engines' and equipment markets' supply curves by the variable cost per unit only. The fixed costs associated with the proposed regulation are calculated to reflect their opportunity costs and then added to the producer surplus decrease after the new market (with-regulation) equilibrium has been established.[D] The primary fixed costs in these markets are associated with one-time expenditures to redesign products and retool production lines to comply with the regulation. These fixed costs can be recovered as part of the industry's routine R&D budget and hence are not likely to lead to additional price increases. This assumption is supported by information received from a number of nonroad engine and equipment manufacturers, with whom EPA met to discuss redesign and equipment costs. The manufacturers indicated that their redesign budgets (for emissions or other product changes) are constrained by R&D budgets that are set annually as a percentage of annual revenues. While the decision to redesign may be driven by anticipated future revenues for an individual piece of equipment, the resources from with the redesign budget is allocated are determined from the current year's R&D budget. Thus redesigns to meet emission standards represent a reallocation of resources that would have been spent for other kinds of R&D (i.e., a lost opportunity cost). To account for the value to the company of this loss, the engineering cost analysis includes a 7 percent rate of return for all fixed costs which are "recovered" over a defined period for the emission compliant products.

An alternative approach for R&D expenditures can be used, in which these costs are included in intermediate-run decision-making. This alternative assumes that manufacturers will change their behavior based on the R&D required for compliance with the standards. A sensitivity analysis is included in Chapter 10 of the draft RIA for this proposal that reflects this approach.

Fixed costs on the refiner side are treated differently in the NDEIM. Unlike for engines and equipment where the fixed costs are primarily for up-front R&D, most of the petroleum refinery fixed costs are for production hardware. The decision to invest to increase, maintain, or decrease production capacity may be made in response to anticipated or actual changes in price. To reflect the different ways in which refiners can pass costs through to refiners, three scenarios were run for the following supply shifts in the diesel fuel markets:

- shift by average total (variable + fixed cost)
- shift by max total (variable + fixed cost)
- shift by max variable cost.

[D] The fixed R&D costs capture the lost opportunity of forgone investments to the firm.

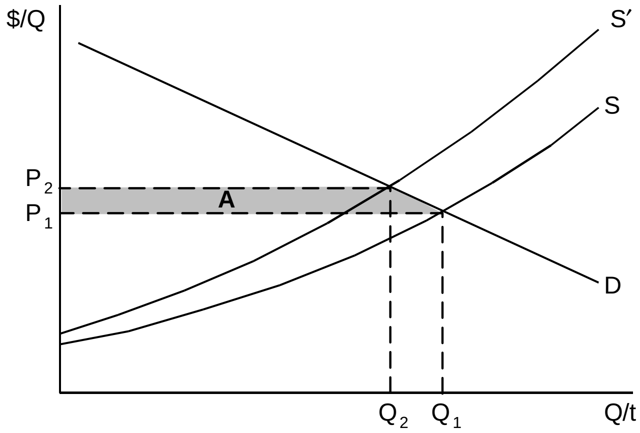
The first, shift by average total cost (variable + fixed), is the primary scenario and is included in the NDEIM. The other two are investigated using sensitivity analyses. These supply shifts are discussed further in sensitivity analysis presented in Appendix10I.

10.2.3.4 Estimation of Social Costs

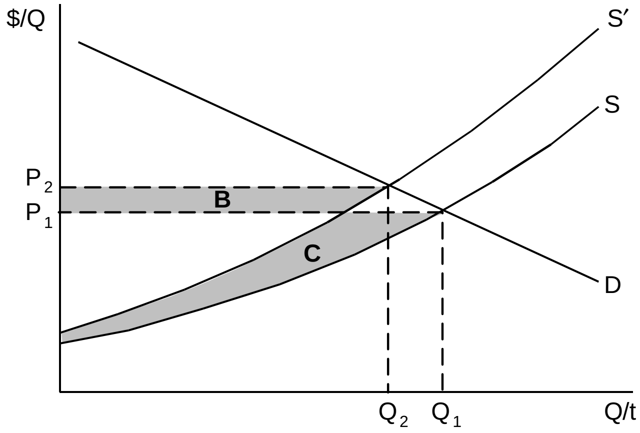
The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net “surplus” changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred to as the “social cost” of a regulation. It is important to emphasize that this measure does not include the benefits that occur outside of the market, that is, the value of the reduced levels of air pollution with the regulations. Including this benefit will reduce the net cost of the regulation and even make it positive.

The demand and supply curves that are used to project market price and quantity impacts can be used to estimate the change in consumer, producer, and total surplus or social cost of the regulation (see Figure 10.2-8).

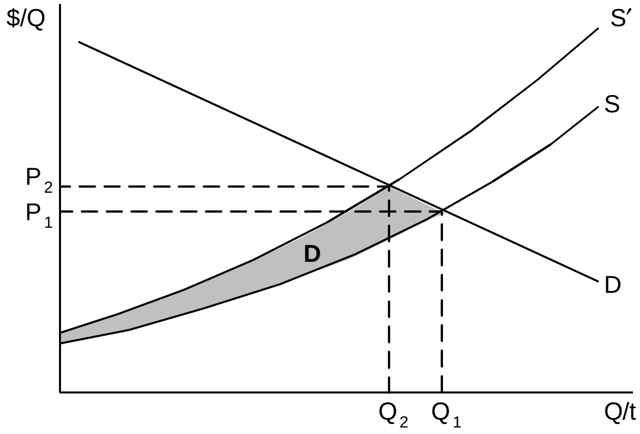
Figure 10.2-8
Market Surplus Changes with Regulation: Consumer and Producer Surplus



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

The difference between the maximum price consumers are willing to pay for a good and the price they actually pay is referred to as “consumer surplus.” Consumer surplus is measured as the area under the demand curve and above the price of the product. Similarly, the difference between the minimum price producers are willing to accept for a good and the price they actually receive is referred to as “producer surplus.” Producer surplus is measured as the area above the supply curve below the price of the product. These areas can be thought of as consumers’ net benefits of consumption and producers’ net benefits of production, respectively.

In Figure 10.2-8, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_1 with quantity Q_1. The increased cost of production with the regulation will cause the market supply curve to shift upward to S'. The new equilibrium price of the product is P_2. With a higher price for the product there is less consumer welfare, all else being unchanged. In Figure 10.2-8(a), area A represents the dollar value of the annual net loss in consumers’ welfare associated with the increased price. The rectangular portion represents the loss in consumer surplus on the quantity still consumed due to the price increase, Q_2, while the triangular area represents the foregone surplus resulting from the reduced quantity consumed, $Q_1 – Q_2$.

In addition to the changes in consumers’ welfare, there are also changes in producers’ welfare with the regulatory action. With the increase in market price, producers receive higher revenues on the quantity still purchased, Q_2. In Figure 10.2-8(b), area B represents the increase in revenues due to this increase in price. The difference in the area under the supply curve up to the original market price, area C, measures the loss in producer surplus, which includes the loss associated with the quantity no longer produced. The net change in producers’ welfare is represented by area B – C.

The change in economic welfare attributable to the compliance costs of the regulations is the sum of consumer and producer surplus changes, that is, – (A) + (B–C). Figure 10.2-8(c) shows the net (negative) change in economic welfare associated with the regulation as area D.[E]

If not all the costs of the regulation are reflected in the supply shift, then the producer and consumer surplus changes reflected in Figure 10.2-5 will not capture the total social costs of the regulation. As discussed earlier, fixed R&D and capital costs are not included in the supply curve shift for the engine and equipment markets. The fixed costs in these instances are assumed to be borne totally by the producers in that none of these costs are passed on to consumers in the form of higher prices. The costs are added to the producer surplus estimates generated from the market analysis so that the accounting accurately reflects the total social cost of the regulation.

[E] However, it is important to emphasize that this measure does not include the benefits that occur outside the market, that is, the value of the reduced levels of air pollution with the regulations. Including this benefit may reduce the net cost of the regulation or even make it positive.

In addition, two additional compliance cost components are included in the total social cost estimates but not integrated in to the market analysis:

- *Operating Costs*: Changes in operating costs are expected to be realized by diesel equipment users, for both existing and new equipment, as a result of the reduced sulfur content of nonroad diesel fuel. These include operating savings (cost reductions) due to fewer oil changes, which accrue to nonroad engines that are already in use as well as those that will comply with the proposed standards. These savings (costs) also include any extra operating costs associated with the new PM emission control technology which may accrue to new engines that use this new technology.
- *Marker costs*: Costs associated with marking high sulfur diesel fuel in the locomotive, marine, and heating oil markets between 2007 and 2014.

Operating costs are not included directly in the model because some of the savings accrue to existing engines and because these savings (costs) are not expected to affect consumer decisions with respect to new engines. Instead, they are added into the estimated welfare impacts as additional costs to the application markets, since it is the users of these engines that will see these savings (costs). Marker costs are not include in the market analysis because locomotive, marine, and heating oil markets are not explicitly modeled in the NDEIM. Similar to the operating savings (costs), marker costs are added into the estimated welfare impacts separately. Nevertheless, a sensitivity analysis was also performed in which these savings (costs) are included as inputs to the NDEIM, where they are modeled as benefits accruing to the application producers. The results of this analysis are presented in Appendix 10.I.

10.3 Economic Impact Modeling

The impact of a regulatory action can be measured by the change in social costs that it generates. Producers will experience economic impacts due to changes in production costs (direct regulatory costs and indirect input price changes) and changes in the market price they receive for their products. Consumers will experience economic impacts due to the adjustments in market prices and their consumption levels.

The previous section described the economic theory that underpins this EIA. This section focuses on the markets and linkages included in the NDEIM. This is followed by a description of the supply and demand elasticities used in the model and an overview of the baseline population data used in the analysis. Finally, the steps used to operationalize the computer model are presented.

10.3.1 Operational Economic Model

The Nonroad Diesel Economic Impact Model simulates the economic impacts using a computer model comprising a series of spreadsheet modules that:

- define the baseline characteristics of the supply and demand of affected commodities and specify the intermarket relationships;
- introduce a policy "shock" into the model based on estimated compliance costs that shift the supply functions;
- use a solution algorithm to determine an estimated new, with-regulation equilibrium price and quantity for all markets; and
- estimate the change in producer and consumer surplus in all markets included in the model.

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium is the result of a series of iterations in which price is adjusted and producers and consumers respond, until a set of stable market prices arises where total market supply equals market demand. Market price adjustment takes place based on a price revision rule, described below, that adjusts price upward (downward) by a given percentage in response to excess demand (excess supply).

The remainder of this section describes elements of the NDEIM including baseline characteristics, compliance cost inputs, model elasticity parameters, and the model solution algorithm.

10.3.2 Baseline Economic Data

This section describes the data needed to run the model. The major components are the baseline data needed to establish the without-regulation equilibrium and the engineering compliance costs that are used to "shock" the model to estimate the with-regulation equilibrium.

10.3.2.1 Baseline Population

The PSR sales data were the primary source for the population for diesel engines used in domestically consumed nonroad diesel equipment (See Chapter 1). Sales data is used as a proxy for production data in the NDEIM because detailed production data by horsepower and equipment application are not available. In addition, modeling inventory decisions of engine and equipment manufacturers is beyond the scope of the NDEIM. EPA adjusted the Power Systems Research (PSR) population to reflect the population units affected by the regulation.[F] Table 10.3-1 lists sales data for affected diesel nonroad equipment consumed domestically in 2000 by engine horsepower and equipment type. The population distribution by size and application is the same

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[F] See Section 8.1 in Chapter 8 of this draft RIA for an explanation of how the engines were allocated to the seven categories.

for engines and equipment because of the one-to-one relationship between engines and equipment.

Baseline nonroad diesel fuel consumption is provided in Table 10.3-2. Fuel consumption is broken out by region (PADD) and application market (construction, agriculture, and manufacturing). Nonroad diesel fuel consumption is further disaggregated into spillover and nonspillover (referred to hereafter as simply nonroad). As described below, spillover fuel is highway grade diesel fuel consumed by nonroad equipment. Spillover fuel is affected by the diesel highway rule and is not affected by this regulation. The economic impact associated with lowering the sulfur content of spillover fuel consumed by nonroad diesel equipment is calibrated into the baseline prior to estimating the economic impacts of the nonroad regulation.[G]

[G] Spillover and nonspillover fuels consumed by nonroad diesel equipment are modeled as two commodities and markets. Thus, in calibrating the baseline, the increased costs associated with the highway rule are used to shock the supply curve for spillover diesel fuel. This results in an increased cost of production in the application markets leading to a slight decrease in application market output. This in turn ripples through the supply chain leading to a very small adjustment (decrease) in the baseline equipment and engine output. The impact of the nonroad rule is then estimated relative to this adjusted baseline.

Table 10.3-1
Engine/Equipment Sales in 2000

Engine Market	Construction	Agricultural Equipment	General Industrial	Generator Sets and Welders	Lawn and Garden	Pumps and Compressors	Refrigeration/Air Condition	Grand Total
$0<hp<25$	17,043	13,195	3,173	54,971	17,118	4,980	8,677	119,159
$25\leq hp<50$	30,233	38,303	6,933	32,540	10,323	4,254	10,394	132,981
$50\leq hp<75$	30,919	19,156	7,074	13,234	1,456	3,930	18,145	93,914
$75\leq hp<100$	30,146	11,788	14,204	5,567	2,722	4,238		68,665
$100\leq hp<175$	49,503	35,226	17,757	7,313	1,556	985		112,340
$175\leq hp<600$	42,126	41,678	8,327	1,813	509	1,494	—	95,947
$hp > 600$ hp	4,945	—	576	1	—	16	—	5,538
Grand Total	204,915	159,347	58,044	115,440	33,684	19,898	37,215	628,543

Table 10.3-2
Nonroad Diesel Equipment, Locomotive and Marine Fuel Consumption in 2001

		Construction (million gallons)	Agriculture (million gallons)	Manufacturing (million gallons)	Total (million gallons)
PADD I&III	Nonroad	1,700	449	2,778	4,927
	Spillover	359	95	1,180	1,634
PADD II	Nonroad	622	992	1,338	2,952
	Spillover	222	355	928	1,505
PADD IV	Nonroad	124	92	164	380
	Spillover	142	105	400	647
PADD V	Nonroad	268	59	373	700
	Spillover	59	13	151	223
Total	Nonroad	2,714	1,592	4,653	8,959
	Spillover	782	568	2,659	4,008

10.3.2.2 Baseline Prices

Prototypical engine and equipment prices were collected for engines by hp size and for diesel equipment by application and horsepower size. Average prices were developed by the Agency based on a review of publicly available market transactions and information listed in the PSR database. Table 10.3-3 provides the prices for the seven engine categories, and Table 10.3-4 provides prices for the 42 diesel equipment categories used in the model.

Table 10.3-3
Baseline Engine Prices

Power Range	Estimated Price
$0<hp<25$	$1,500
$25\leq hp<50$	$2,500
$50\leq hp<75$	$3,000
$75\leq hp<100$	$4,000
$100\leq hp<175$	$5,500
$175\leq hp<600$	$20,000
hp > 600 hp	$125,000

Table 10.3-4
Baseline Prices of Nonroad Diesel Equipment

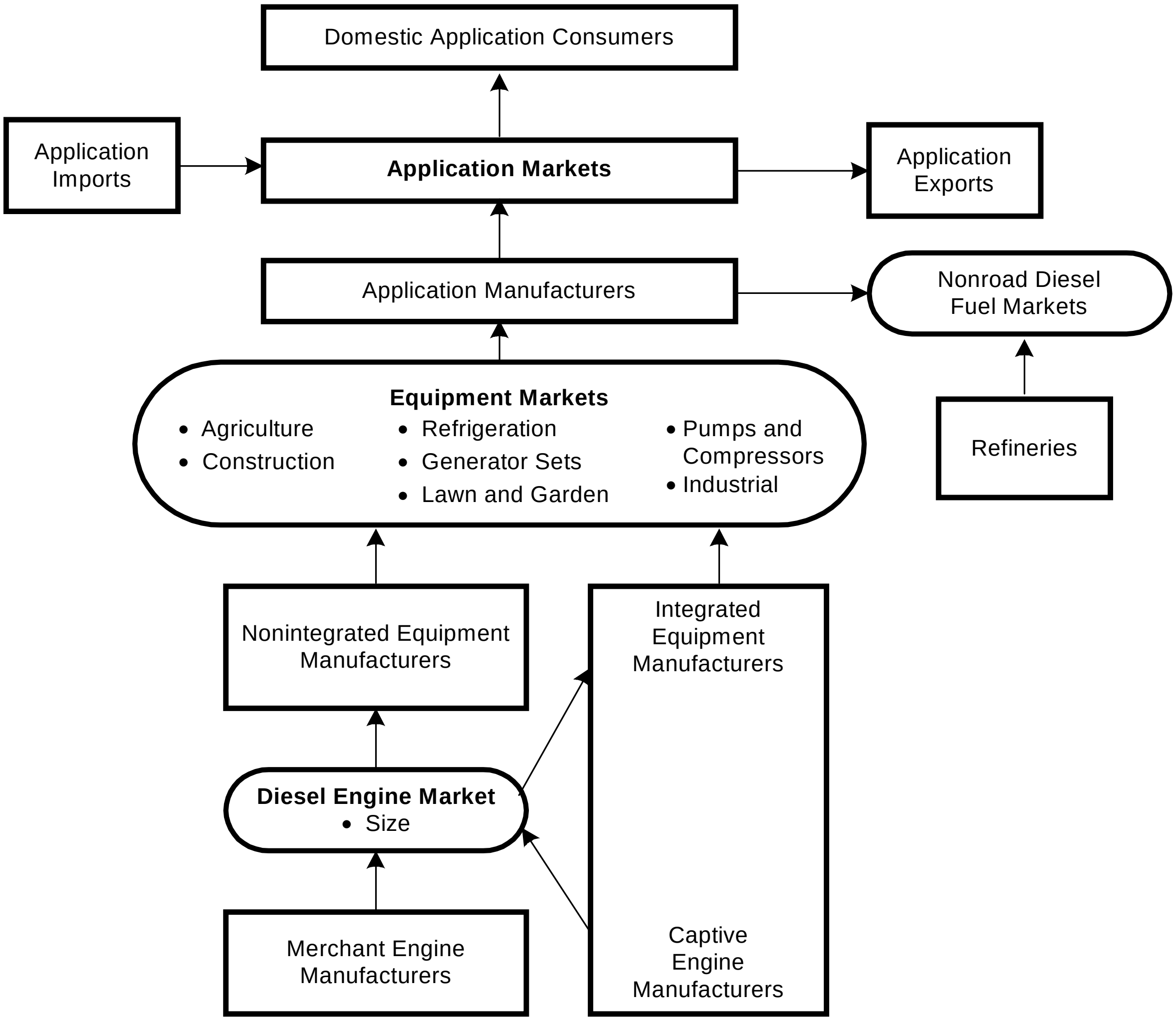
Application	<25 hp	26-50 hp	51-75 hp	76-100 hp	101-175 hp	176-600 hp	>600 hp
Construction Equip	$3,500	$13,500	$25,000	$50,000	$100,000	$575,000	$700,000
Agricultural Equip	$3,000	$6,000	$23,500	$47,000	$70,000	$130,000	N/A
Pumps & Compressors	$1,500	$3,000	$11,000	$21,500	$32,000	$60,000	$88,000
GenSets & Welders	$3,500	$6,000	$25,000	$50,000	$75,000	$140,000	N/A
Refrigeration & A/C	$1,500	$3,000	$11,000	N/A	N/A	N/A	N/A
General Industrial	$3,500	$13,500	$25,000	$50,000	$100,000	$575,000	$700,000
Lawn & Garden	$3,000	$6,000	$23,500	$47,000	$70,000	$130,000	N/A

10.3.3 Market Linkages

Figure 10.3-1 illustrates the sectoral linkages and the market interactions between producers and consumers that are explicitly accounted for in the NDEIM. This section provides a brief discussion of each of these related markets and important linkages. A detailed description of the market model equations (supply and demand functions, equilibrium conditions) is provided in Appendix 10F.

One of the key features of the NDEIM is that a subset of related markets is modeled together, with sector linkages; hence, selected interaction effects, are explicitly specified and accounted for in the model. A brief discussion of the markets and important linkages are highlighted in this section. Detailed specifications of the market model equations (supply and demand functions, equilibrium conditions) are provided in Appendix 10F.

Figure 10.3-1
Multimarket Linkages in the Engine/Equipment/Fuel Supply Chain



10.3.3.1 Engine Markets

The engine markets are the markets associated with the production and consumption of engines. Seven separate engine markets were modeled segmented by engine size in horsepower (the EIA includes more horsepower categories than the standards, allowing more efficient use of the engine compliance cost estimates developed for this proposal):

- less than 25 hp,
- 26 to 50 hp,
- 51 to 75 hp,
- 76 to 100 hp,
- 101 to 175 hp,

- 176 to 600 hp, and
- greater than 601 hp.

An important feature of the engine and equipment markets is that many equipment manufacturers also produce engines. These equipment manufacturers are referred to as integrated manufacturers, and their facilities produce engines to consume internally (in the nonroad equipment they produce) and to supply to the engine markets (to other equipment manufacturers). An important modeling distinction is that all compliance costs for internally consumed engines are absorbed into the equipment costs of integrated suppliers. In contrast, nonintegrated equipment suppliers pay some portion of the engine compliance costs that is determined by the incremental market price for engines. As long as engine demand is not perfectly inelastic, the increased market price for engines will reflect only a partial pass through of engine compliance costs. For the purposes of this analysis, engines sold on the market are referred to as “merchant” engines, and engines consumed internally are referred to as “captive” engines.

Because the impact of the regulation is not directly proportional to engine price, the relative supply shift in each of the engine size markets varies. For example, the ratio of control costs to market price for small engines (less than 25 hp) is approximately 12 percent, and the ratio of control costs to market price for large engines (greater than 600 hp) is approximately 8 percent. These different ratios lead to different relative shifts in the supply curves and larger percentage changes in market price and quantity in the small engine markets. The impacts on the engine market and engine manufacturers can be found in Appendix 10A.

10.3.3.2 Equipment Markets

The equipment markets are the markets associated with the production and consumption of equipment that use nonroad diesel engines. Seven equipment types were modeled:

- construction,
- agricultural,
- pumps and compressors,
- generators and welder sets,
- refrigeration and air conditioning,
- general industrial, and
- lawn and garden.

These categories were identified by reviewing the “application” field in the PSR database. Approximately 60 different equipment “applications” are listed in the database. These were aggregated into these seven equipment categories to obtain a manageable number of individual markets to be included in the NDEIM.[H] For each of these equipment types, up to seven

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[H] See Section 8.1 in Chapter 8 of this draft RIA for an explanation of how the engines were allocated to the seven categories.

horsepower size category markets are included in the model, for a total of 42 individual equipment markets.[I]

Equipment manufacturers consume engines in their production processes and then supply diesel equipment to the application markets. The demand for engines is determined by the production levels in the application markets. Equipment is assumed to be a fixed factor of production in the application markets. Thus, for example, a 1 percent decrease in agricultural output will lead to a 1 percent decrease in the demand for agricultural equipment (and fuel). The relationship between the percentage increase on equipment price and the percentage change in equipment demand (the elasticity of demand) is determined by the input share of diesel equipment relative to other inputs in the application markets and the supply and demand elasticities in the application markets. The impacts on the equipment market and manufacturers can be found in Appendix 10B.

10.3.3.3 Application Markets

The application markets consist of the producers and consumers of products and services that employ the diesel engines, equipment, and fuel affected by this proposal. Therefore, these economic entities are indirectly affected by the proposal, through potential changes in equipment and fuel prices. For the purpose of this analysis, application markets are grouped into three categories:

- construction
- agricultural, and
- manufacturing.

These three application markets were selected because they encompass the majority of the final products and services that incorporate diesel engines in their production process. In addition, these three application markets represent a manageable number of markets to be included in the NDEIM and have well-established census data. The impacts on the equipment market and manufacturers can be found in Appendix 10C.

The seven equipment categories are mapped into the three application markets as described in Table 10.3-5.

[I] There are seven horsepower/application categories that do not have sales in 2000 and are not included in the model. These are: agricultural equipment >600 hp; gensets & welders > 600 hp; refrigeration & A/C > 71 hp (4 hp categories); and lawn & garden >600 hp. Therefore, the total number of diesel equipment markets is 42 rather than 49.

Table 10.3-5
Mapping from Equipment Markets to Application Markets

Application Market	Equipment Market
Construction	Construction equipment Pumps and compressors Gen sets and welding equipment
Agricultural	Agricultural equipment
Manufacturing	Refrigeration Lawn and garden General industrial

For example, mining equipment is included in the general industrial equipment categories. This is linked to the manufacturing applications market.[J]

10.3.3.4 Diesel Fuel Markets

The analysis estimates the economic impact of increasing the cost of production for nonroad diesel, locomotive, and marine fuels. Nonroad diesel fuel cost increases are linked to application markets (users of diesel engines and equipment) to estimate how the compliance costs on refineries are linked to the application markets. For example, although locomotive and commercial marine engines and equipment are not directly affected by the proposed rule, the users of this equipment in the application markets are affected by the higher diesel fuel costs, and these impacts are included in the model.

As shown in Figure 10.2-8, equipment users are the suppliers in the application markets and are also the demanders of nonroad diesel fuel. Thus, the fuel markets are linked with the engine and equipment markets through the application markets using the derived-demand framework described above.

One can think of these relationships as the conceptual equivalent of the derived-demand relationship between equipment and engines. For example, the demand for No. 2 distillate will be specified as a function of the production and consumption decisions made in the construction, agricultural, and manufacturer application markets. In this way increased equipment costs decrease the demand for fuel, and increased fuel costs decrease the demand for equipment because both increase the costs of production in the application markets. This in turn leads to a

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[J] A full mapping from PSR applications to the NDEIM equipment categories and then to the NDEIM application markets can be found in a Memorandum from M. Gallaher, RTI, to Todd Sherwood, Clarifications on Several Modeling Issues (March 24, 2003).

decrease in production in the application markets and hence a decrease in the demand for inputs (fuel and equipment).

Eight nonroad diesel fuel markets were modeled: two distinct nonroad diesel fuel commodities in four regional markets. The two fuels are:

- 500 ppm nonroad diesel fuel, and
- 15 ppm nonroad diesel fuel.

The four regional nonroad diesel fuel markets are

- PADD 1 and 3,
- PADD 2,
- PADD 4, and
- PADD 5 (includes Alaska and Hawaii)

Separate compliance costs are estimated for each 500 ppm and 15 ppm regional fuel market. As a result, the price and quantify impacts, as well as the changes in producer surplus, vary across the eight fuel markets. PADD 1 and PADD 3 are combined because of the high level of interregional trade. Regional imports and exports across the remaining four regions included in the model are not included in the analysis. The impacts on the nonroad fuel market can be found in Appendix 10D.

As discussed in Section 10.2, all the engine and equipment markets are modeled as competitive: it is assumed that no individual firm can affect the market price. In this case the average compliance cost is used to shift the market supply curve. In this scenario, the fuel markets are also modeled as competitive, and each regional supply curve is shifted by the average total (variable + fixed) regional cost of the regulation. This fuel market scenario (referred to as average total cost) is also used when presenting disaggregated market results in Appendices 10.A through 10.D and sensitivity analysis results in Appendix 10I.

However, in some fuel regions, it may be more appropriate to let the “high cost” refinery’s compliance cost drive the new market price. Under this assumption it is the high cost producer’s dollars per gallon compliance cost increase that determines the new price. This is referred to as the max cost scenario and no longer reflects perfect competition because now individual firms have direct influence on market price. Two max cost scenarios are explored in the sensitivity analysis presented in Appendix 10I: one in which the high-cost refinery’s total (variable + fixed) compliance costs determine price, and a second in which only the high-cost refinery’s variable compliance costs determine price.

Locomotive and Marine Diesel. Locomotive and marine fuels are modeled as being consumed by the manufacturers. Thus, these fuels are included in the total volume of diesel fuel consumed by the manufacturing application market and their per unit (gallon) costs are included in the refinery supply function shifts. Inclusion of locomotive and marine diesel fuel in the market analysis has two main impacts:

- It affects the magnitude of the supply shift because their per unit costs are slightly different from the nonroad diesel per-unit fuel costs
- It increases the quantity of affected diesel fuel purchased by the manufacturing market and thus increases the total compliance costs passed into the manufacturing sector from refiners. This leads to a greater shift of the supply curve in the manufacturing application market and thus a larger decrease in quantity in the manufacturing market that ripples back through the fuel, equipment, and engine markets.

10.3.3.5 Calibrating the Spillover Baseline (Impacts Relative to Highway Rule)

The economic impact of the nonroad diesel rule is measured relative to the highway diesel rule. The highway rule is scheduled to be phased in prior to the nonroad rule. Thus, the effect of the highway rule must be incorporated into the baseline prior to modeling the impact of the nonroad rule. The main factor to be addressed is “spillover” fuel from the highway market. The Agency estimates that approximately one-third of nonroad equipment currently uses highway grade fuel because of access and distribution factors. Nonroad equipment currently using highway diesel will experience increased fuel costs as a result of the highway rule, but not as a result of the nonroad rule. These costs have already been captured in the highway rule analysis; thus, it is important to discount “spillover” fuel in the nonroad market to avoid double counting of cost impacts.

In the model, the increased cost of “spillover” fuel consumed by nonroad equipment is built into the baseline. In effect, current market projections are “shocked” by the highway rule and a new set of baseline prices and quantities is estimated for all linked markets. This then becomes the new baseline from which the incremental impact of the nonroad rule is estimated. When this adjustment is performed, increasing the cost of producing spillover fuel leads to a slight increase in the cost of producing goods and services in the application markets, and a decrease in application quantity ripples through the derived-demand curves of the equipment and engine markets, slightly reducing the baseline equipment and engine population. We assume that there are no substitutions between spillover diesel fuel consumption and nonroad diesel fuel consumption as prices change because demand is primarily driven by availability constraints.

10.3.4 Compliance Costs

Social costs capture the full range of economic impacts associated with the proposed regulation. For this economic analysis, the sources of compliance costs are grouped in to the following categories:

- Fixed and variable costs for diesel engines
- Fixed and variable costs for diesel equipment
- Fixed and variable costs for nonroad diesel fuel
- Changes in operating costs of diesel equipment
- Marker costs for locomotive and marine diesel fuel and heating oil.

All of the above compliance impact are included in the social cost estimates. The majority are included in the market analysis using the NDEIM. However, as discussed above, not all of the compliance costs are incorporated in to the market analysis. Table 10.3-6 identifies which compliance costs are used as shocks in the market analysis and which are added to the social cost estimates after changes in market prices and quantifies have been determined.

Table 10.3-6
How Compliance Costs are Accounted for in the Economic Analysis

Compliance Costs used to Shock the Market Model	Compliance Costs added after Market Analysis
• Variable costs for diesel engines • Variable costs for diesel equipment • Fixed and variable costs for nonroad diesel fuel	• Fixed costs for diesel engines • Fixed costs for diesel equipment • Changes in operating costs of diesel equipment • Marker costs for locomotive and marine diesel fuel and heating oil

The compliance costs described in Chapters 6 and 7 were used to determine the regulation's impacts on each industry sector. The compliance cost per unit varied over time and by industry sector (engine, equipment, or fuel producer). All costs are presented in 2001 dollars and most are broken out by variable and fixed costs.

10.3.4.1 Engine and Equipment Compliance Costs

For diesel engines, the projected compliance costs are largely due to using new technologies, such as advanced emissions control technologies and low-sulfur diesel fuel, to meet the proposed Tier 4 emissions standards. Compliance costs for engines are broken out by horsepower category and impact year. The per unit compliance costs are weighted average costs within the appropriate horsepower range (refer to Chapter 6 for how we have estimated engine and equipment costs; refer to Chapter 8 for aggregate costs and projected sales; per unit costs within each horsepower range are the engine and equipment aggregate costs for that horsepower range divided by the projected sales for that horsepower range). As shown in Table 10.3-7, the fixed cost per engine typically decreases after 5 years as these annualized costs are depreciated. The regulation's market impacts are driven primarily by the per-engine variable costs that remain relatively constant over time. In 2013, there is a projected fourfold cost increase for engines in the range of 25 hp to less than 75 hp, which then decreases over time. Because these engines represent over 35 percent of the overall engine population, this cost increase contributes to the year 2013 having the largest average cost per unit impact.

For nonroad equipment, the majority of the projected compliance cost increases are due to the need to redesign the equipment. The fixed cost consists of the redesign cost to accommodate new emissions control devices. The variable cost consists of the cost of new or modified equipment hardware and of labor to install the new emissions control devices. The per unit compliance costs are weighted average costs within the appropriate horsepower range.

The equipment sector compliance costs are broken out by horsepower category and impact year in Table 10.3-8. The majority of costs per piece of equipment are the fixed costs. The overall compliance costs per piece of equipment are less than half the overall costs associated with the same horsepower category engine. Table 10.3-8 shows a significant compliance cost increase for equipment in the range of 25 hp to less than 75 hp in the year 2013.

10.3.4.2 Nonroad Diesel Fuel Compliance Costs

In the fuel market, the desulfurization (compliance) costs per gallon of diesel fuel differ according to PADD and according to impact year as shown in Table 10.3-9a,b,c. Sulfur fuel requirements are phased in a two-step process. From 2007 to 2010, both the nonroad sector and the locomotive and marine sectors are required to meet the sulfur standard of 500ppm. The costs for this combined 500ppm market are shown in Table 10.3-9a. Variable and fixed costs per gallon are presented for the average cost refiner and the maximum cost refiner in each PADD.

Beginning in 2010, the costs diverge between these two groups. 2010 is the target year set for nonroad diesel fuel to meet a 15 ppm capacity sulfur standard, while the sulfur standard for marine and locomotive diesel fuel will remain at 500 ppm. Therefore, nonroad diesel fuel is estimated to experience a higher increase in cost than locomotive and marine diesel fuel, after 2010, as shown in Tables 10.3-9b and 10.3-9c, respectively.

Table 10.3-7
Compliance Costs per Engine[a]

HP Category	Cost Types	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0<hp<25	Variable	$131	$131	$124	$124	$124	$124	$124	$124	$124	$124	$124
	Fixed	$30	$29	$29	$28	$27	$0	$0	$0	$0	$0	$0
	Total	$161	$161	$153	$152	$152	$124	$124	$124	$124	$124	$124
25≤hp<50	Variable	$149	$149	$141	$141	$141	$852	$852	$457	$647	$647	$647
	Fixed	$47	$46	$45	$44	$43	$61	$60	$59	$58	$57	$0
	Total	$196	$195	$186	$185	$184	$913	$912	$516	$705	$704	$647
50≤hp<75	Variable	$171	$171	$161	$161	$161	$845	$845	$642	$642	$642	$642
	Fixed	$48	$47	$46	$45	$44	$62	$61	$60	$59	$58	$0
	Total	$218	$217	$207	$206	$205	$9073	$906	$702	$701	$700	$642
75≤hp<100	Variable	$0	$0	$0	$0	$1,150	$1,150	$1,139	$1,139	$1,139	$1,139	$1,139
	Fixed	$0	$0	$0	$0	$53	$52	$70	$69	$55	$18	$17
	Total	$0	$0	$0	$0	$1,2046	$1,203	$1,209	$1,208	$1,194	$1,157	$1,157
100≤hp<175	Variable	$0	$0	$0	$0	$1,410	$1,410	$1,384	$1,384	$1,384	$1,384	$1,384
	Fixed	$0	$0	$0	$0	$52	$51	$68	$67	$53	$17	$17
	Total	$0	$0	$0	$0	$1,461	$1,461	$1,452	$1,450	$1,436	$1,401	$1,400
175≤hp<600	Variable	$0	$0	$0	$2,266	$1,265	$1,755	$2,209	$2,209	$2,208	$2,207	$2,206
	Fixed	$0	$0	$0	$199	$188	$185	$240	$236	$66	$56	$55
	Total	$0	$0	$0	$2,466	$2,453	$1,939	$2,450	$2,445	$2,2742	$2,262	$2,261
hp≥600hp	Variable	$0	$0	$0	$5,402	$5,402	$4,216	$6,952	$6,952	$6,953	$6,953	$6,953
	Fixed	$0	$0	$0	$904	$825	$813	$1,222	$1,205	$479	$403	$398
	Total	$0	$0	$0	$6,306	$6,228	$5,030	$8,175	$8,157	$7,432	$7,356	$7,351

(continued)

Table 10.3-7 (continued)
Compliance Costs per Engine[a]

HP Category	Cost Types	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0<hp<25	Variable	$124	$124	$124	$124	$124	$124	$124	$124	$124	$124	$124	$124
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$124	$124	$124	$124	$124	$124	$124	$124	$124	$124	$124	$124
25≤hp<50	Variable	$647	$647	$647	$647	$647	$647	$647	$647	$647	$647	$647	$647
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$647	$647	$647	$647	$647	$647	$647	$647	$647	$647	$647	$647
50≤hp<75	Variable	$642	$642	$642	$642	$642	$642	$642	$642	$642	$642	$642	$642
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$642	$642	$642	$642	$642	$642	$642	$642	$642	$642	$642	$642
75≤hp<100	Variable	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139	$1,139
100≤hp<175	Variable	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384	$1,384
175≤hp<600	Variable	$2,205	$2,204	$2,203	$2,202	$2,202	$2,201	$2,200	$2,200	$2,199	$2,198	$2,198	$2,197
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$2,205	$2,2042	$2,203	$2,202	$2,202	$2,201	$2,200	$2,200	$2,199	$2,198	$2,198	$2,197
hp≥600hp	Variable	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,954
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,953	$6,954

[a] 2001 dollars

Table 10.3-8
Costs per Piece of Equipment

HP Category	Cost Types	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0<hp<25	Variable	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$10	$10	$10	$9	$9	$9	$9	$9	$8	$8	$0
	Total	$10	$10	$10	$9	$9	$9	$9	$9	$8	$8	$0
25≤hp<50	Variable	$0	$0	$0	$0	$0	$18	$18	$18	$18	$18	$18
	Fixed	$12	$12	$12	$11	$11	$41	$40	$39	$38	$38	$27
	Total	$12	$12	$12	$11	$11	$58	$58	$57	$56	$56	$45
50≤hp<75	Variable	$0	$0	$0	$0	$0	$18	$18	$18	$18	$18	$18
	Fixed	$12	$12	$12	$12	$12	$45	$44	$43	$43	$42	$31
	Total	$12	$12	$12	$12	$12	$62	$62	$61	$60	$60	$48
75≤hp<100	Variable	$0	$0	$0	$0	$55	$55	$55	$55	$55	$55	$55
	Fixed	$0	$0	$0	$0	$90	$89	$109	$107	$105	$104	$102
	Total	$0	$0	$0	$0	$145	$143	$164	$162	$160	$159	$157
100≤hp<175	Variable	$0	$0	$0	$0	$55	$55	$55	$55	$55	$55	$55
	Fixed	$0	$0	$0	$0	$140	$138	$170	$167	$164	$162	$159
	Total	$0	$0	$0	$0	$196	$193	$225	$223	$220	$217	$215
175≤hp<600	Variable	$0	$0	$0	$92	$91	$91	$91	$91	$91	$91	$91
	Fixed	$0	$0	$0	$322	$317	$312	$384	$379	$373	$368	$362
	Total	$0	$0	$0	$414	$409	$404	$476	$470	$464	$459	$453
hp≥600hp	Variable	$0	$0	$0	$125	$125	$125	$181	$181	$181	$181	$181
	Fixed	$0	$0	$0	$743	$732	$721	$1,071	$1,056	$1,041	$1,026	$1,012
	Total	$0	$0	$0	$868	$857	$846	$1,252	$1,237	$1,222	$1,207	$1,193

(continued)

Table 10.3-8 (continued)
Costs per Piece of Equipment

HP Category	Cost Types	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0<hp<25	Variable	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
25≤hp<50	Variable	$18	$18	$18	$18	$18	$18	$18	$18	$18	$18	$18	$18
	Fixed	$27	$26	$26	$25	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$44	$44	$44	$43	$18	$18	$18	$18	$18	$18	$18	$18
50≤hp<75	Variable	$18	$18	$18	$18	$18	$18	$18	$18	$18	$18	$18	$18
	Fixed	$30	$30	$29	$29	$0	$0	$0	$0	$0	$0	$0	$0
	Total	$48	$48	$47	$47	$18	$18	$18	$18	$18	$18	$18	$18
75≤hp<100	Variable	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55
	Fixed	$101	$99	$98	$19	$19	$0	$0	$0	$0	$0	$0	$0
	Total	$155	$154	$152	$74	$74	$55	$55	$55	$55	$55	$55	$55
100≤hp<175	Variable	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55	$55
	Fixed	$157	$155	$153	$30	$30	$0	$0	$0	$0	$0	$0	$0
	Total	$213	$210	$208	$86	$85	$55	$55	$55	$55	$55	$55	$55
175≤hp<600	Variable	$91	$91	$91	$91	$90	$90	$90	$90	$90	$90	$90	$90
	Fixed	$357	$352	$69	$69	$68	$0	$0	$0	$0	$0	$0	$0
	Total	$448	$443	$160	$159	$158	$90	$90	$90	$90	$90	$90	$90
hp≥600hp	Variable	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181	$181
	Fixed	$998	$985	$327	$323	$319	$0	$0	$0	$0	$0	$0	$0
	Total	$1,180	$1,166	$508	$504	$500	$181	$181	$181	$181	$181	$181	$181

Table 10.3-9a
Desulfurization Costs for Nonroad, Locomotive, and Marine Diesel Fuel by PADD Prior 2010

	Average Cost		Maximum Cost	
	Variable Costs ($/gallon)	Fixed Costs ($/gallon)	Variable Costs ($/gallon)	Fixed Costs ($/gallon)
PADD I and III	0.0089	0.0063	0.0129	0.0207
PADD II	0.0143	0.0158	0.0228	0.0254
PADD IV	0.0144	0.0268	0.0174	0.0403
PADD V	0.0089	0.0165	0.0097	0.0296

Table 10.3-9b
Desulfurization Costs for Nonroad Diesel Fuel by PADD Starting in 2010

	Average Cost		Maximum Cost	
	Variable Costs ($/gallon)	Fixed Costs ($/gallon)	Variable Costs ($/gallon)	Fixed Costs ($/gallon)
PADD I and III	0.0184	0.0117	0.0251	0.0287
PADD II	0.0247	0.0364	0.0285	0.0459
PADD IV	0.0280	0.0611	0.0301	0.0624
PADD V	0.0194	0.0391	0.0191	0.0649

Table 10.3-9c
Desulfurization Costs for Marine and Locomotive Diesel Fuel by PADD Starting in 2010

	Average Cost		Maximum Cost	
	Variable Costs ($/gallon)	Fixed Costs ($/gallon)	Variable Costs ($/gallon)	Fixed Costs ($/gallon)
PADD I and III	0.0088	0.0071	0.0089	0.0247
PADD II	0.0169	0.0188	0.0228	0.0254
PADD IV	0.0111	0.0225	0.0114	0.0254
PADD V	0.0080	0.0137	0.0064	0.0154

10.3.4.3 Changes in Operating Costs

Changes in operating costs are expected to be realized by all diesel equipment users as a result of the reduced sulfur content of nonroad diesel fuel. Equipment operating saving are generated as a result of the decreased sulfur content of diesel fuel. These savings will accrue to all equipment users that use 500 ppm or 15 ppm sulfur fuel, regardless of whether the equipment has a compliant engine or not. In addition, there may be some operating costs associated with the new PM emission reduction technology. These costs will accrue to engines that use these new technologies. Both of these impacts are discussed in more detail in Chapter 4 and 5. These costs are not included in the market analysis and are instead listed as a separate category in the social cost results tables. In Appendix 10I, a sensitivity analysis is presented where operating cost savings are introduced into the market analysis as a downward shift in the application supply functions.

The net impact is projected to be operating savings of between 1 to 17 cents per gallon consumed by nonroad diesel equipment. Operating savings vary depending on the horsepower size of the equipment (smaller engines have greater savings) and whether the equipment has emission controls (existing noncontrolled fleet will have greater savings). Table 10.3-10 lists the new operating savings by horsepower category and by existing versus new (emission controls) fleet. Average cost savings per gallon for nonroad applications will vary by year as the existing fleet of diesel equipment is replaced over time. EPA estimates that approximately 90 percent of the existing fleet will be replaced by 2030.

Table 10.3-10
Net Change in Operating Cost[a]

Engine Size/Type	Net Operating Cost Per Gallon—Existing Fleet	Net Operating Cost Per Gallon—New Fleet
0<hp<25	–$0.160	–$0.175
25≤hp<50	–$0.076	–$0.041
50≤hp<75	–$0.066	–$0.036
75≤hp<175	–$0.030	–$0.014
175≤hp<600	–$0.017	–$0.010
hp≥600	–$0.011	–$0.006
Locomotive	–$0.011	N/A
Marine	–$0.011	N/A

[a] Changes in operating costs are shown as negative values to indicate savings (benefits).

10.3.4.4 Fuel Marker Costs

Fuel marker costs will be needed to identify high-sulfur diesel fuel in the locomotive, marine, and heating oil markets as the proposed regulation is phased in between 2007 and 2014. These are also added as a separate category in the social cost result tables. Marker costs are estimated to be 0.2 cents per gallon. The affected fuel volume is presented in Table 10.3-11.

Table 10.3-11
Fuel Volume Affected by Marker Costs of 0.2 Cents per Gallon

Year	Locomotive and Marine (MMgals/yr)	Heating Oil (MMgals/yr)
2007		4371
2008		7563
2009		7633
2010	2082	3210
2011	3621	
2012	3647	
2013	3670	
2014	1539	

10.3.5 Supply and Demand Elasticity Estimates

To operationalize the market model, supply and demand elasticities are needed to represent the behavior adjustments that are likely to be made by market participants. The following parameters are needed:

- supply and demand price elasticities for application markets (construction, agriculture, and manufacturing),
- supply elasticities for equipment markets,
- supply elasticities for engine markets, and
- supply elasticities for diesel fuel markets.

Note that, for the equipment, engine, and diesel fuel markets, demand-specific elasticity estimates are not needed because they are derived internally as a function of changes in output levels in the applications markets.

Tables 10.3-12 and 10.3-13 provides a summary of the demand and supply elasticities used to estimate the economic impact of the proposed rule. Most elasticities were derived econometrically using publicly available data, with the exception of the supply elasticities for the construction and agricultural application markets and the diesel fuel supply elasticity, which were obtained from previous studies.[K] The general methodologies for estimating the supply and demand elasticities are discussed below. The specific regression results are presented in Appendix 10G. It should be noted that these elasticities reflect intermediate run behavioral

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[K] A supply function was estimated as part of the simultaneous equations approach used for the construction and manufacturing application markets. However, the supply elasticity estimates were not statistically significant and were negative, which is inconsistent with generally accepted economic theory. For this reason, literature estimates were used for the supply elasticities in the construction and manufacturing application markets.

changes. In the long run, supply and demand are expected to be more elastic since more substitutes may become available.

Table 10.3-12
Summary of Market Demand Elasticities Used in the NDEIM

Market	Estimate	Source	Method	Input Data Summary
Applications				
Construction	–0.96	EPA econometric estimate	Simultaneous equation (log-log) approach	Annual time series from 1958 – 1995 developed by Jorgenson et al. (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987)
Agriculture	–0.20	EPA econometric estimate	Productivity shift approach (Morgenstern, Pizer, and Shih, 2002)	Annual time series from 1958 – 1995 developed by Jorgenson et al. (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987)
Manufacturing	–0.58	EPA econometric estimate	Simultaneous equation (log-log) approach.	Annual time series from 1958 – 1995 developed by Jorgenson et al. (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987)
Equipment				
Construction		Derived demand	In the derived demand approach, • compliance costs increase prices and decrease demand for products and services in the application markets; • this in turn leads to reduced demand for diesel equipment, engines and fuel, which are inputs into the production of products and services in the application markets	
Agriculture		Derived demand		
Pumps/ compressors		Derived demand		
Generators and Welders		Derived demand		
Refrigeration		Derived demand		
Industrial		Derived demand		
Lawn and Garden		Derived demand		
Engines		Derived demand		
Diesel fuel		Derived demand		

Table 10.3-13
Summary of Market Supply Elasticities Used in the NDEIM

Markets	Estimate	Source	Method	Input Data Summary
Applications				
Construction	1.0	Literature-based estimate	Based on Topel and Rosen, (1988).[a]	Census data, 1963 – 1983
Agriculture	0.32	Literature-based estimate	Production-weighted average of individual crop estimates ranging from 0.27 to 0.55. (Lin et al., 2000)	Agricultural Census data 1991 – 1995
Manufacturing	1.0	Literature-based estimate	Literature estimates are not available so assumed same value as for Construction market	Not applicable
Equipment				
Construction	3.31	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3531
Agriculture	2.14	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3523
Pumps/ compressors	2.83	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3561 and 3563
Generators/ Welder Sets	2.91	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3548
Refrigeration	2.83	EPA econometric estimate		Assumed same as pumps/compressors
Industrial	5.37	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3537
Lawn and Garden	3.37	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3524
Engines	3.81	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3519
Diesel fuel	0.24	Literature based estimate	Based on Considine (2002).[b]	From Energy Intelligence Group (EIG); 1987-2000

[a] Most other studies estimate ranges that encompass 1.0, including DiPasquale (1997) and DiPasquale and Wheaton (1994).

[b] Other estimates range from 0.02 to 1.0 (Greene and Tishchishyna, 2000). However, Considine (2002) is one of the few studies that estimates a supply elasticity for refinery operations. Most petroleum supply elasticities also include extraction.

10.3.6 Model Solution Algorithm

The algorithm for determining with-regulation equilibria can be summarized by six recursive steps:

1. Impose the control costs on affected supply segments, thereby affecting their supply decisions.
2. Recalculate the market supply in each market. Excess demand currently exists.
3. Determine the new prices via a price revision rule. We use a rule similar to the factor price revision rule described by Kimbell and Harrison (1986). P_i is the market price at iteration i, q_d is the quantity demanded, and q_s is the quantity supplied. The parameter z influences the magnitude of the price revision and speed of convergence. The revision rule increases the price when excess demand exists, lowers the price when excess supply exists, and leaves the price unchanged when market demand equals market supply. The price adjustment is expressed as follows:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s} \right)^z \qquad (10.1)$$

4. Recalculate market supply with new prices, accounting for fuel-switching choices associated with new energy prices.
5. Compute market demand in each market.
6. Compare supply and demand in each market. If equilibrium conditions are not satisfied, go to Step 3, resulting in a new set of market prices. Repeat until equilibrium conditions are satisfied (i.e., the ratio of supply and demand is arbitrarily close to one). When the ratio is appropriately close to one, the market-clearing condition of supply equals demand is satisfied.

Section 10.1 presents a summary of the results of this modeling. More detailed information is presented in the appendices to this chapter.

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APPENDIX 10A: Impacts on the Engine Market and Engine Manufacturers

This appendix provides the time series of impacts from 2007 through 2030 for the engine markets. Seven separate engine markets were modeled segmented by engine size in horsepower (the EIA includes more horsepower categories than the standards, allowing more efficient use of the engine compliance cost estimates developed for this proposal):

- less than 25 hp,
- 26 to 50 hp,
- 51 to 75 hp,
- 76 to 100 hp,
- 101 to 175 hp,
- 176 to 600 hp, and
- greater than 601 hp.

Tables 10A-1 through 10A-7 provide the time series of impacts for the seven horsepower markets included in the analysis. Each table includes the following:

- average engine price,
- average engineering costs (variable and fixed) per engine,
  - Note that in the engineering cost analysis, fixed costs for engine manufacturers are recovered in the first five years (see Chapter 6)
- absolute change in the market price ($),
  - Note that the estimated absolute change in market price is based on variable costs only; see Appendix I for a sensitivity analysis including fixed costs as well
- relative change in market price (%),
- relative change in market quantity (%),
- total engineering (regulatory) costs for merchant engines ($), and
- change in producer surplus from merchant engine manufacturers.

As described in Section 10.3.3.1, approximately 65 percent of engines are sold on the market and these are referred to as “merchant” engines. The remaining 35 percent are consumed internally by integrated equipment manufacturers and are referred to as “captive” engines. The total engineering costs and changes in producer surplus presented in this appendix include only merchant engines because captive engines never pass through the engines markets. Fixed and variable engineering costs and changes in producer surplus associated with captive engines are included in equipment manufacture impact estimates presented in Appendix 10B.

All prices and costs are presented in $2001, and real engine prices are assumed to be constant. The engineering cost per engine typically decreases after 5 years as the annualized fixed costs are depreciated. The price increase after that time is driven by the per-engine variable costs and remains relatively constant over time. We did the cost analysis using a 3% discount rate. We will also be conducting a similar analysis using a 7% discount rate and including this information in the docket.

For all the engine size categories, the majority of the cost of the regulation is passed along through increased engine prices. Price increases range from $125 (8.3% increase) for small (<25hp) engines to $6,950 (5.6% increase) for large (>600hp) engines. Even though the cost per engine and market impacts (in terms of percentage change in price and quantity) stabilize in the later years of the regulation, the engineering costs and producer surplus changes continue to gradually increase because the projected baseline population of engines increases over time.

Table 10A-1. Impacts on the Engine Market and Engine Manufacturers: ≤25hp (Average Price per Engine = $1,500)[a]

	Engine (≤25Hp)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (10^3)	Change in Producer Surplus for Engine Manufacturers (10^3)
2007	—	–$0.01	0.00%	–0.002%	$–	–$1.0
2008	$161.48	$131.33	8.76%	–0.003%	$19,922.9	–$3,720.4
2009	$160.69	$131.33	8.76%	–0.003%	$20,361.4	–$3,720.4
2010	$153.07	$124.45	8.30%	–0.004%	$19,906.8	–$3,721.1
2011	$152.35	$124.45	8.30%	–0.006%	$20,322.4	–$3,722.4
2012	$151.67	$124.44	8.30%	–0.009%	$20,738.0	–$3,723.8
2013	$124.47	$124.43	8.30%	–0.010%	$17,434.5	–$5.5
2014	$124.47	$124.43	8.30%	–0.010%	$17,850.1	–$5.9
2015	$124.47	$124.43	8.30%	–0.010%	$18,265.7	–$5.6
2016	$124.47	$124.43	8.30%	–0.010%	$18,681.3	–$5.9
2017	$124.47	$124.43	8.30%	–0.010%	$19,096.9	–$6.0
2018	$124.47	$124.43	8.30%	–0.010%	$19,512.5	–$6.1
2019	$124.47	$124.43	8.30%	–0.010%	$19,928.1	–$6.3
2020	$124.47	$124.43	8.30%	–0.010%	$20,343.7	–$6.4
2021	$124.47	$124.43	8.30%	–0.010%	$20,759.3	–$6.5
2022	$124.47	$124.43	8.30%	–0.010%	$21,174.9	–$6.6
2023	$124.47	$124.43	8.30%	–0.010%	$21,590.5	–$6.8
2024	$124.47	$124.43	8.30%	–0.010%	$22,006.1	–$6.9
2025	$124.47	$124.43	8.30%	–0.010%	$22,421.7	–$7.0
2026	$124.47	$124.43	8.30%	–0.010%	$22,837.3	–$7.1
2027	$124.47	$124.43	8.30%	–0.010%	$23,252.8	–$7.3
2028	$124.47	$124.43	8.30%	–0.010%	$23,668.4	–$7.4
2029	$124.47	$124.43	8.30%	–0.010%	$24,084.0	–$7.5
2030	$124.47	$124.43	8.30%	–0.010%	$24,499.6	–$7.6
NPV[b]					$308,900.8	–$15,668.6

[a] Figures are in 2001 dollars.
[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10A-2. Impacts on the Engine Market and Engine Manufacturers: 26–50hp (Average Price per Engine = $2,500)[a]

	Engine (26hp to 50hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Engine Manufacturers (10^3)**
2007	—	–$0.02	0.00%	–0.002%	$–	–$2.0
2008	$196.04	$149.22	5.97%	–0.003%	$26,120.5	–$6,238.9
2009	$195.05	$149.22	5.97%	–0.003%	$26,553.3	–$6,238.9
2010	$186.18	$141.30	5.65%	–0.005%	$25,887.0	–$6,240.5
2011	$185.27	$141.28	5.65%	–0.008%	$26,296.9	–$6,244.0
2012	$184.39	$141.26	5.65%	–0.012%	$26,706.8	–$6,247.3
2013	$913.48	$852.28	34.09%	–0.013%	$134,957.6	–$9,042.7
2014	$912.31	$852.27	34.09%	–0.014%	$137,429.7	–$9,043.7
2015	$516.20	$457.31	18.29%	–0.013%	$79,257.9	–$9,043.0
2016	$704.91	$647.10	25.88%	–0.013%	$110,276.3	–$9,043.6
2017	$703.86	$647.10	25.88%	–0.013%	$112,153.3	–$9,043.8
2018	$647.19	$647.10	25.88%	–0.013%	$105,000.1	–$13.8
2019	$647.19	$647.10	25.88%	–0.013%	$106,877.1	–$14.1
2020	$647.19	$647.10	25.88%	–0.013%	$108,754.1	–$14.3
2021	$647.19	$647.10	25.88%	–0.013%	$110,631.1	–$14.5
2022	$647.19	$647.10	25.88%	–0.013%	$112,508.1	–$14.8
2023	$647.19	$647.10	25.88%	–0.013%	$114,385.1	–$15.0
2024	$647.19	$647.10	25.88%	–0.013%	$116,262.1	–$15.3
2025	$647.19	$647.10	25.88%	–0.013%	$118,139.1	–$15.5
2026	$647.19	$647.10	25.88%	–0.013%	$120,016.1	–$15.7
2027	$647.19	$647.10	25.88%	–0.013%	$121,893.1	–$16.0
2028	$647.19	$647.10	25.88%	–0.013%	$123,770.1	–$16.2
2029	$647.19	$647.10	25.88%	–0.013%	$125,647.0	–$16.5
2030	$647.19	$647.10	25.88%	–0.013%	$127,524.0	–$16.7
NPV[b]					$1,363,271.2	–$58,965.6

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table10.A-3. Impacts on the Engine Market and Engine Manufacturers: 51–75hp (Average Price per Engine = $3,000)[a]

	Engine (51hp to 75hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Engine Manufacturers (10^3)**
2007	—	–$0.02	0.00%	–0.002%	—	–$1.5
2008	$218.10	$170.53	5.68%	–0.003%	$18,456.1	–$4,025.4
2009	$217.24	$170.53	5.68%	–0.003%	$18,723.8	–$4,025.4
2010	$206.87	$160.99	5.37%	–0.005%	$18,155.5	–$4,026.7
2011	$206.07	$160.96	5.37%	–0.009%	$18,408.3	–$4,029.4
2012	$205.29	$160.93	5.36%	–0.012%	$18,661.1	–$4,032.0
2013	$907.16	$844.59	28.15%	–0.013%	$83,885.0	–$5,785.8
2014	$906.11	$844.58	28.15%	–0.014%	$85,210.9	–$5,786.6
2015	$702.27	$641.75	21.39%	–0.013%	$67,144.2	–$5,786.0
2016	$701.29	$641.75	21.39%	–0.014%	$68,151.8	–$5,786.4
2017	$700.35	$641.75	21.39%	–0.014%	$69,159.3	–$5,786.6
2018	$641.85	$641.75	21.39%	–0.014%	$64,390.8	–$10.8
2019	$641.85	$641.75	21.39%	–0.014%	$65,398.3	–$10.9
2020	$641.85	$641.75	21.39%	–0.014%	$66,405.8	–$11.1
2021	$641.85	$641.74	21.39%	–0.014%	$67,413.4	–$11.2
2022	$641.85	$641.74	21.39%	–0.014%	$68,420.9	–$11.4
2023	$641.85	$641.74	21.39%	–0.014%	$69,428.4	–$11.6
2024	$641.85	$641.74	21.39%	–0.014%	$70,435.9	–$11.7
2025	$641.85	$641.74	21.39%	–0.014%	$71,443.5	–$11.9
2026	$641.85	$641.74	21.39%	–0.014%	$72,451.0	–$12.1
2027	$641.84	$641.74	21.39%	–0.014%	$73,458.5	–$12.2
2028	$641.84	$641.74	21.39%	–0.014%	$74,466.0	–$12.4
2029	$641.84	$641.74	21.39%	–0.014%	$75,473.6	–$12.5
2030	$641.84	$641.73	21.39%	–0.014%	$76,481.1	–$12.7
NPV[b]					$855,626.8	–$37,885.0

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table10A-4. Impacts on the Engine Market and Engine Manufacturers: 76–100hp (Average Price per Engine = $4,000)[a]

	Engine (76hp to 100hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Engine Manufacturers (10^3)**
2007	—	–$0.02	0.00%	–0.002%	—	–$1.3
2008	—	–$0.03	0.00%	–0.003%	—	–$1.7
2009	—	–$0.03	0.00%	–0.003%	—	–$1.7
2010	—	–$0.05	0.00%	–0.005%	—	–$2.8
2011	—	–$0.09	0.00%	–0.009%	—	–$5.1
2012	$1,203.59	$1,150.18	28.75%	–0.012%	$68,915.0	–$3,058.0
2013	$1,202.69	$1,150.17	28.75%	–0.013%	$70,054.5	–$3,058.9
2014	$1,209.39	$1,139.20	28.48%	–0.014%	$71,643.2	–$4,158.0
2015	$1,208.24	$1,139.22	28.48%	–0.013%	$72,771.9	–$4,157.6
2016	$1,194.15	$1,139.22	28.48%	–0.014%	$73,105.8	–$3,363.2
2017	$1,157.02	$1,139.22	28.48%	–0.014%	$71,978.6	–$1,107.4
2018	$1,156.74	$1,139.22	28.48%	–0.014%	$73,107.3	–$1,107.6
2019	$1,139.37	$1,139.22	28.48%	–0.014%	$73,137.5	–$9.3
2020	$1,139.37	$1,139.23	28.48%	–0.014%	$74,266.2	–$9.4
2021	$1,139.37	$1,139.23	28.48%	–0.014%	$75,394.9	–$9.5
2022	$1,139.37	$1,139.23	28.48%	–0.014%	$76,523.6	–$9.7
2023	$1,139.38	$1,139.23	28.48%	–0.014%	$77,652.3	–$9.8
2024	$1,139.38	$1,139.23	28.48%	–0.014%	$78,781.0	–$9.9
2025	$1,139.38	$1,139.24	28.48%	–0.014%	$79,909.7	–$10.1
2026	$1,139.38	$1,139.24	28.48%	–0.014%	$81,038.4	–$10.2
2027	$1,139.38	$1,139.24	28.48%	–0.014%	$82,167.0	–$10.4
2028	$1,139.39	$1,139.24	28.48%	–0.014%	$83,295.7	–$10.5
2029	$1,139.39	$1,139.24	28.48%	–0.014%	$84,424.4	–$10.6
2030	$1,139.39	$1,139.25	28.48%	–0.014%	$85,553.1	–$10.8
NPV[b]					$882,138.1	–$14,777.3

[a] Figures are in 2001 dollars.
[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10A-5. Impacts on the Engine Market and Engine Manufacturers: 101–175hp (Average Price per Engine = $15,500)[a]

	Engine (101hp to 175hp)					
Year	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (10^3)	Change in Producer Surplus for Engine Manufacturers (10^3)
2007	—	–$0.04	0.00%	–0.002%	—	–$2.0
2008	—	–$0.04	0.00%	–0.003%	—	–$2.6
2009	—	–$0.05	0.00%	–0.003%	—	–$2.7
2010	—	–$0.07	0.00%	–0.005%	—	–$4.5
2011	—	–$0.14	0.00%	–0.010%	—	–$8.6
2012	$1,461.38	$1,409.45	25.63%	–0.014%	$91,426.0	–$3,248.7
2013	$1,460.54	$1,409.44	25.63%	–0.015%	$92,886.1	–$3,250.0
2014	$1,451.52	$1,383.48	25.15%	–0.016%	$93,816.2	–$4,397.7
2015	$1,450.45	$1,383.50	25.15%	–0.015%	$95,249.4	–$4,397.0
2016	$1,436.25	$1,383.49	25.15%	–0.015%	$95,804.6	–$3,519.5
2017	$1,400.64	$1,383.49	25.15%	–0.015%	$94,879.5	–$1,161.4
2018	$1,400.38	$1,383.49	25.15%	–0.015%	$96,312.7	–$1,161.6
2019	$1,383.71	$1,383.49	25.15%	–0.015%	$96,599.4	–$15.3
2020	$1,383.71	$1,383.49	25.15%	–0.015%	$98,032.6	–$15.5
2021	$1,383.71	$1,383.49	25.15%	–0.015%	$99,465.8	–$15.7
2022	$1,383.71	$1,383.49	25.15%	–0.015%	$100,899.1	–$15.9
2023	$1,383.71	$1,383.49	25.15%	–0.015%	$102,332.3	–$16.2
2024	$1,383.71	$1,383.49	25.15%	–0.015%	$103,765.5	–$16.4
2025	$1,383.71	$1,383.49	25.15%	–0.015%	$105,198.8	–$16.6
2026	$1,383.71	$1,383.49	25.15%	–0.015%	$106,632.0	–$16.8
2027	$1,383.71	$1,383.49	25.15%	–0.015%	$108,065.2	–$17.0
2028	$1,383.71	$1,383.49	25.15%	–0.015%	$109,498.4	–$17.3
2029	$1,383.71	$1,383.49	25.15%	–0.015%	$110,931.7	–$17.5
2030	$1,383.71	$1,383.49	25.15%	–0.015%	$112,364.9	–$17.7
NPV[b]					$1,161,715.6	–$15,656.9

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10A-6. Impacts on the Engine Market and Engine Manufacturers: 176–600hp (Average Price per Engine = $20,000)[a]

Year	Engine (176hp to 600hp)					Change in Producer Surplus for Engine Manufacturers (10^3)
	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (10^3)	
2007	—	$0.13	0.00%	–0.003%	—	–$5.0
2008	—	$0.17	0.00%	–0.003%	—	–$6.4
2009	—	$0.17	0.00%	–0.003%	—	–$6.6
2010	—	$0.28	0.00%	–0.005%	—	–$11.2
2011	$2,465.89	$2,265.86	11.33%	–0.010%	$99,063.4	–$8,035.8
2012	$2,452.90	$2,264.55	11.32%	–0.015%	$100,109.1	–$7,687.3
2013	$1,939.41	$1,753.89	8.77%	–0.016%	$80,391.8	–$7,690.4
2014	$2,449.55	$2,208.60	11.04%	–0.017%	$103,103.5	–$10,142.1
2015	$2,445.00	$2,207.69	11.04%	–0.016%	$104,474.2	–$10,140.4
2016	$2,273.55	$2,206.73	11.03%	–0.016%	$98,601.2	–$2,897.9
2017	$2,262.31	$2,205.82	11.03%	–0.016%	$99,559.5	–$2,486.1
2018	$2,260.63	$2,204.94	11.02%	–0.016%	$100,930.2	–$2,486.6
2019	$2,204.93	$2,204.08	11.02%	–0.016%	$99,852.3	–$38.4
2020	$2,204.09	$2,203.25	11.02%	–0.016%	$101,223.0	–$38.9
2021	$2,203.28	$2,202.43	11.01%	–0.016%	$102,593.7	–$39.5
2022	$2,202.49	$2,201.64	11.01%	–0.016%	$103,964.4	–$40.0
2023	$2,201.72	$2,200.87	11.00%	–0.016%	$105,335.1	–$40.5
2024	$2,200.97	$2,200.13	11.00%	–0.016%	$106,705.8	–$41.0
2025	$2,200.24	$2,199.40	11.00%	–0.016%	$108,076.5	–$41.6
2026	$2,199.53	$2,198.69	10.99%	–0.016%	$109,447.2	–$42.1
2027	$2,198.84	$2,197.99	10.99%	–0.016%	$110,817.9	–$42.6
2028	$2,198.16	$2,197.32	10.99%	–0.016%	$112,188.6	–$43.2
2029	$2,197.50	$2,196.66	10.98%	–0.016%	$113,559.4	–$43.7
2030	$2,196.86	$2,196.02	10.98%	–0.016%	$114,930.1	–$44.2
NPV[b]					$1,280,605.9	–$39,033.9

[a] Figures are in 2001 dollars.
[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10A-7. Impacts on the Engine Market and Engine Manufacturers: ≥601hp (Average Price per Engine = \$125,000)[a]

	Engine (≥601hp)					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Engine Manufacturers (10^3)**
2007	—	–\$0.80	0.00%	–0.002%	—	–\$1.2
2008	—	–\$1.00	0.00%	–0.003%	—	–\$1.6
2009	—	–\$1.00	0.00%	–0.003%	—	–\$1.6
2010	—	–\$1.65	0.00%	–0.005%	—	–\$2.6
2011	\$6,305.92	\$5,399.16	4.32%	–0.009%	\$10,293.4	–\$1,480.2
2012	\$6,227.66	\$5,397.83	4.32%	–0.013%	\$10,320.1	–\$1,375.2
2013	\$5,029.76	\$4,211.73	3.37%	–0.014%	\$8,459.7	–\$1,375.9
2014	\$8,174.82	\$6,947.29	5.56%	–0.016%	\$13,952.2	–\$2,095.1
2015	\$8,157.40	\$6,947.67	5.56%	–0.015%	\$14,124.8	–\$2,094.7
2016	\$7,432.01	\$6,947.66	5.56%	–0.015%	\$13,053.0	–\$850.7
2017	\$7,356.03	\$6,947.74	5.56%	–0.015%	\$13,102.0	–\$727.2
2018	\$7,350.56	\$6,947.82	5.56%	–0.015%	\$13,274.6	–\$727.3
2019	\$6,952.78	\$6,947.90	5.56%	–0.015%	\$12,728.6	–\$8.9
2020	\$6,952.86	\$6,947.98	5.56%	–0.015%	\$12,901.2	–\$9.0
2021	\$6,952.93	\$6,948.05	5.56%	–0.015%	\$13,073.7	–\$9.2
2022	\$6,953.00	\$6,948.13	5.56%	–0.015%	\$13,246.3	–\$9.3
2023	\$6,953.07	\$6,948.20	5.56%	–0.015%	\$13,418.9	–\$9.4
2024	\$6,953.13	\$6,948.27	5.56%	–0.015%	\$13,591.4	–\$9.5
2025	\$6,953.20	\$6,948.33	5.56%	–0.015%	\$13,764.0	–\$9.6
2026	\$6,953.26	\$6,948.40	5.56%	–0.015%	\$13,936.5	–\$9.7
2027	\$6,953.33	\$6,948.46	5.56%	–0.015%	\$14,109.1	–\$9.9
2028	\$6,953.39	\$6,948.53	5.56%	–0.015%	\$14,281.7	–\$10.0
2029	\$6,953.45	\$6,948.59	5.56%	–0.015%	\$14,454.2	–\$10.1
2030	\$6,953.50	\$6,948.65	5.56%	–0.015%	\$14,626.8	–\$10.2
NPV[b]					\$160,049.3	–\$8,057.4

[a] Figures are in 2001 dollars.
[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

APPENDIX 10B: Impacts on Equipment Market and Equipment Manufacturers

This appendix provides the time series of impacts from 2007 through 2030 for the equipment markets. The equipment markets are the markets associated with the production and consumption of equipment that use nonroad diesel engines. Seven equipment types were modeled:

- construction,
- agricultural,
- pumps and compressors,
- generators and welder sets,
- refrigeration and air conditioning,
- general industrial, and
- lawn and garden.

Forty-two equipment markets were modeled, representing 7 horsepower categories within 7 application categories. There are 7 horsepower/application categories that did not have sales in 2000 and are not included in the model, so the total number of diesel equipment markets is 42 rather than 49.

Tables 10B-1 through 10B-7 provide the time series of impacts for the seven equipment markets included in the analysis. Each table includes the following:

- average equipment price,
- average engineering costs (variable and fixed) per piece of equipment,
  - Note that in the engineering cost analysis, fixed costs for equipment manufacturers are recovered in the first ten years (see Chapter 6)
- absolute change in the equipment market price ($),
  - Note that the estimated absolute change in market price is based on variable costs only; see Appendix I for a sensitivity analysis including fixed costs as well
- relative change in the equipment market price (%),
- relative change in the equipment market quantity (%),
- total engineering (regulatory) costs associated with each equipment market ($), and
- change in producer surplus for all equipment manufacturers in the market.

As described in Section 10.3.3.1, approximately 65 percent of engines are sold on the market and these are referred to as “merchant” engines. The remaining 35 percent are consumed internally by integrated equipment manufacturers and are referred to as “captive” engines. The engineering costs and changes in producer surplus presented in this appendix include total equipment costs as well as captive engine costs. Because captive engines never pass through the engines markets, they therefore present an additional cost for integrated equipment producers.

All prices and costs are presented in $2001, and real equipment prices are assumed to be constant. The engineering cost per piece of equipment peak around 2013 as the fixed cost per equipment are phased in and then are depreciated over the next several years.

A greater percentage of the cost of the regulation is borne by the various equipment markets than is borne by the engine market. However, a substantial percentage of the cost is still passed along through increased equipment prices. Price increases range from an average increase of 1.84 percent in the general industrial equipment market to 9.37 percent in the refrigeration and air-conditioning market. Even though the cost per piece of equipment and market impacts (in terms of percentage change in price and quantity) stabilize after the initial years of the regulation, the engineering costs and produce surplus changes continue to gradually increase because the projected baseline population of equipment increases over time.

Table 10B-1. Impacts on Agricultural Equipment Market and Manufacturers (Average Price per Equipment = $55,396)[a]

	Agricultural Equipment					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Equipment Manufacturers (10^3)**
2007	–$0.01	–$0.71	0.00%	–0.003%	$–	–$129.1
2008	$80.60	$67.81	1.09%	–0.003%	$6,411.0	–$2,412.3
2009	$80.52	$67.96	1.09%	–0.003%	$6,499.3	–$2,415.8
2010	$76.73	$63.67	1.04%	–0.006%	$6,353.8	–$2,560.5
2011	$796.90	$658.43	1.49%	–0.013%	$132,042.2	–$27,655.9
2012	$1,242.25	$1,060.42	2.13%	–0.017%	$196,410.2	–$36,985.4
2013	$1,386.50	$1,193.96	5.41%	–0.019%	$199,850.0	–$39,869.9
2014	$1,533.64	$1,300.28	5.49%	–0.020%	$231,071.2	–$49,179.7
2015	$1,405.61	$1,176.51	3.76%	–0.019%	$224,459.1	–$49,121.5
2016	$1,409.97	$1,222.04	4.55%	–0.019%	$222,759.7	–$40,985.7
2017	$1,396.93	$1,220.45	4.55%	–0.019%	$223,659.0	–$39,136.9
2018	$1,380.70	$1,218.91	4.56%	–0.019%	$223,742.8	–$36,472.6
2019	$1,362.36	$1,217.42	4.56%	–0.019%	$223,224.0	–$33,205.5
2020	$1,358.70	$1,215.97	4.57%	–0.019%	$225,988.3	–$33,221.7
2021	$1,286.32	$1,214.58	4.57%	–0.019%	$212,477.8	–$16,963.0
2022	$1,252.67	$1,213.22	4.58%	–0.019%	$207,735.7	–$9,472.8
2023	$1,241.18	$1,211.91	4.58%	–0.019%	$208,148.7	–$7,137.7
2024	$1,215.51	$1,210.63	4.58%	–0.019%	$204,967.8	–$1,208.5
2025	$1,214.27	$1,209.39	4.59%	–0.019%	$207,732.1	–$1,224.7
2026	$1,213.06	$1,208.19	4.59%	–0.019%	$210,496.4	–$1,240.8
2027	$1,211.88	$1,207.02	4.59%	–0.019%	$213,260.7	–$1,256.9
2028	$1,210.74	$1,205.88	4.60%	–0.019%	$216,025.0	–$1,273.1
2029	$1,209.63	$1,204.78	4.60%	–0.019%	$218,789.4	–$1,289.2
2030	$1,208.55	$1,203.71	4.60%	–0.019%	$221,553.7	–$1,305.3
NPV[b]			3.76%		$2,632,706.9	–$306,693.1

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10.B-2. Impacts on Construction Equipment Market and Manufacturers
(Average Price per Equipment = $166,086)[a]

	Construction Equipment					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Equipment Manufacturers (10^3)**
2007	–$0.02	–$1.57	0.00%	–0.003%	—	–$366.2
2008	$66.22	$58.01	0.61%	–0.004%	$2,983.7	–$1,985.4
2009	$66.23	$58.14	0.61%	–0.004%	$3,011.4	–$1,994.8
2010	$62.97	$53.39	0.58%	–0.007%	$2,954.9	–$2,409.1
2011	$785.33	$648.33	0.68%	–0.014%	$139,136.4	–$35,069.1
2012	$1,359.19	$1,166.79	1.38%	–0.020%	$230,575.9	–$50,141.3
2013	$1,452.08	$1,252.19	2.60%	–0.021%	$221,136.2	–$53,022.7
2014	$1,647.81	$1,396.67	2.62%	–0.023%	$266,895.3	–$67,782.3
2015	$1,551.03	$1,304.51	2.05%	–0.022%	$267,893.0	–$67,679.2
2016	$1,537.78	$1,331.79	2.27%	–0.022%	$260,863.2	–$57,507.7
2017	$1,523.40	$1,330.14	2.27%	–0.022%	$261,235.8	–$54,852.6
2018	$1,512.99	$1,328.54	2.28%	–0.022%	$262,618.9	–$53,208.1
2019	$1,491.27	$1,326.99	2.28%	–0.022%	$260,590.1	–$48,151.8
2020	$1,487.37	$1,325.50	2.28%	–0.022%	$263,663.6	–$48,197.6
2021	$1,414.60	$1,324.04	2.28%	–0.022%	$245,876.8	–$27,383.1
2022	$1,372.58	$1,322.63	2.29%	–0.022%	$236,856.8	–$15,335.5
2023	$1,362.50	$1,321.27	2.29%	–0.022%	$237,399.6	–$12,850.7
2024	$1,331.08	$1,319.94	2.29%	–0.022%	$231,100.5	–$3,524.0
2025	$1,329.77	$1,318.65	2.29%	–0.022%	$234,174.0	–$3,569.9
2026	$1,328.51	$1,317.40	2.29%	–0.022%	$237,247.5	–$3,615.7
2027	$1,327.27	$1,316.18	2.29%	–0.022%	$240,321.0	–$3,661.6
2028	$1,326.07	$1,315.00	2.30%	–0.022%	$243,394.5	–$3,707.4
2029	$1,324.91	$1,313.85	2.30%	–0.022%	$246,468.0	–$3,753.2
2030	$1,323.77	$1,312.73	2.30%	–0.022%	$249,541.6	–$3,799.0
NPV[b]			1.89%		$3,006,380.6	–$433,600.5

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10B-3. Impacts on Pumps and Compressor Equipment Market and Manufacturers (Average Price per Equipment = $13,198)[a]

Year	Pumps and Compressors					Change in Producer Surplus for Equipment Manufacturers (10^3)
	Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (10^3)	
2007	–$0.03	–$0.12	0.00%	–0.002%	—	–$2.1
2008	$107.28	$99.50	3.69%	–0.002%	$183.9	–$186.7
2009	$107.24	$99.63	3.70%	–0.002%	$183.9	–$186.7
2010	$101.82	$94.34	3.51%	–0.003%	$183.9	–$187.3
2011	$296.63	$265.84	3.81%	–0.003%	$949.8	–$785.9
2012	$637.09	$581.71	5.18%	–0.005%	$1,968.1	–$1,442.0
2013	$900.62	$833.50	11.57%	–0.006%	$2,506.4	–$1,782.1
2014	$940.17	$862.60	11.61%	–0.006%	$2,836.5	–$2,099.1
2015	$813.80	$737.70	8.43%	–0.006%	$2,848.8	–$2,098.3
2016	$851.85	$777.12	9.80%	–0.006%	$2,861.0	–$2,098.8
2017	$849.14	$775.75	9.80%	–0.006%	$2,873.2	–$2,098.9
2018	$840.21	$774.42	9.81%	–0.006%	$2,701.6	–$1,915.1
2019	$837.80	$773.14	9.81%	–0.006%	$2,713.8	–$1,915.2
2020	$835.47	$771.91	9.82%	–0.006%	$2,726.0	–$1,915.4
2021	$813.71	$770.71	9.82%	–0.006%	$2,140.5	–$1,317.7
2022	$790.85	$769.56	9.82%	–0.006%	$1,498.3	–$663.3
2023	$778.71	$768.44	9.83%	–0.006%	$1,172.3	–$325.3
2024	$767.62	$767.35	9.83%	–0.006%	$867.7	–$8.6
2025	$766.57	$766.30	9.83%	–0.006%	$880.0	–$8.7
2026	$765.55	$765.29	9.84%	–0.006%	$892.2	–$8.8
2027	$764.57	$764.30	9.84%	–0.006%	$904.4	–$8.9
2028	$763.61	$763.35	9.84%	–0.006%	$916.6	–$9.1
2029	$762.68	$762.42	9.85%	–0.006%	$928.9	–$9.2
2030	$761.78	$761.52	9.85%	–0.006%	$941.1	–$9.3
NPV[b]			8.29%		$24,133.3	–$14,701.0

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10.B-4. Impacts on Generator Sets and Welding Equipment Market and Manufacturers (Average Price per Equipment = $14,483)[a]

Year	Generator Sets and Welders: Engineering Cost/Unit	Absolute Change in Price	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (10^3)	Change in Producer Surplus for Equipment Manufacturers (10^3)
2007	–$0.01	–$0.11	0.00%	–0.002%	—	–$13.5
2008	$143.56	$124.60	2.61%	–0.002%	$7,583.3	–$2,696.7
2009	$143.18	$124.66	2.62%	–0.002%	$7,697.0	–$2,696.9
2010	$136.20	$118.07	2.48%	–0.003%	$7,536.0	–$2,700.7
2011	$175.95	$152.11	2.51%	–0.003%	$11,229.4	–$3,630.6
2012	$330.33	$292.14	2.74%	–0.005%	$25,160.7	–$5,944.6
2013	$607.35	$559.14	6.37%	–0.006%	$40,598.4	–$7,666.3
2014	$614.82	$562.28	6.37%	–0.006%	$42,375.4	–$8,531.3
2015	$482.77	$431.32	4.48%	–0.006%	$37,298.3	–$8,526.4
2016	$530.87	$482.22	5.34%	–0.006%	$39,279.4	–$8,225.8
2017	$527.13	$481.18	5.34%	–0.006%	$39,499.6	–$7,924.0
2018	$510.92	$480.17	5.34%	–0.006%	$37,501.4	–$5,403.8
2019	$508.22	$479.21	5.34%	–0.006%	$37,816.3	–$5,196.6
2020	$506.76	$478.28	5.34%	–0.006%	$38,339.1	–$5,197.4
2021	$501.54	$477.38	5.34%	–0.006%	$38,153.4	–$4,489.7
2022	$490.14	$476.51	5.33%	–0.006%	$36,762.9	–$2,577.2
2023	$479.37	$475.68	5.33%	–0.006%	$35,418.0	–$710.3
2024	$475.15	$474.87	5.33%	–0.006%	$35,285.3	–$55.7
2025	$474.37	$474.09	5.33%	–0.006%	$35,808.1	–$56.4
2026	$473.62	$473.34	5.33%	–0.006%	$36,330.8	–$57.2
2027	$472.89	$472.61	5.33%	–0.006%	$36,853.6	–$58.0
2028	$472.18	$471.90	5.33%	–0.006%	$37,376.3	–$58.8
2029	$471.50	$471.22	5.33%	–0.006%	$37,899.1	–$59.5
2030	$470.83	$470.55	5.33%	–0.006%	$38,421.8	–$60.3
NPV[b]			4.59%		$461,276.2	–$59,177.6

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10B-5. Impacts on Refrigeration and Air-Conditioning Equipment Market and Manufacturers (Average Price per Equipment = $6,314)[a]

	Refrigeration and Air Conditioning					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Equipment Manufacturers (10^3)**
2007	–$0.02	–$0.06	0.00%	–0.002%	—	–$1.9
2008	$166.67	$154.86	4.28%	–0.002%	$528.8	–$531.3
2009	$166.37	$154.80	4.29%	–0.002%	$528.8	–$531.3
2010	$157.66	$146.32	4.07%	–0.003%	$528.8	–$531.9
2011	$157.36	$146.24	4.08%	–0.003%	$528.8	–$532.6
2012	$157.08	$146.14	4.09%	–0.005%	$528.8	–$534.1
2013	$712.79	$678.12	13.88%	–0.006%	$2,382.7	–$1,726.8
2014	$711.32	$677.31	13.88%	–0.006%	$2,394.6	–$1,727.0
2015	$504.88	$471.52	9.34%	–0.006%	$2,406.5	–$1,726.3
2016	$556.92	$524.16	11.11%	–0.006%	$2,418.4	–$1,726.7
2017	$555.81	$523.64	11.12%	–0.006%	$2,430.4	–$1,726.8
2018	$545.06	$523.14	11.12%	–0.006%	$1,913.4	–$1,198.1
2019	$544.20	$522.66	11.12%	–0.006%	$1,925.4	–$1,198.2
2020	$543.37	$522.19	11.12%	–0.006%	$1,937.3	–$1,198.3
2021	$542.56	$521.74	11.13%	–0.006%	$1,949.2	–$1,198.4
2022	$541.78	$521.31	11.13%	–0.006%	$1,961.1	–$1,198.5
2023	$521.01	$520.88	11.13%	–0.006%	$782.0	–$7.7
2024	$520.60	$520.48	11.13%	–0.006%	$794.0	–$7.8
2025	$520.21	$520.08	11.14%	–0.006%	$805.9	–$7.9
2026	$519.82	$519.70	11.14%	–0.006%	$817.8	–$8.0
2027	$519.45	$519.32	11.14%	–0.006%	$829.7	–$8.1
2028	$519.09	$518.96	11.14%	–0.006%	$841.6	–$8.2
2029	$518.74	$518.61	11.14%	–0.006%	$853.5	–$8.3
2030	$518.40	$518.27	11.15%	–0.006%	$865.4	–$8.4
NPV[b]			9.37%		$20,342.3	–$12,244.8

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10.B-6. Impacts on General Industrial Equipment Market and Manufacturers (Average Price per Equipment = $132,972)[a]

	General Industrial					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Equipment Manufacturers (10^3)**
2007	–$0.04	–$0.51	0.00%	–0.002%	—	–$31.7
2008	$51.50	$46.14	0.44%	–0.002%	$606.1	–$366.3
2009	$51.51	$46.25	0.44%	–0.002%	$611.4	–$366.9
2010	$48.95	$43.66	0.42%	–0.003%	$600.4	–$375.5
2011	$485.64	$425.67	0.49%	–0.003%	$7,449.8	–$4,335.3
2012	$1,289.38	$1,159.24	1.52%	–0.005%	$27,094.6	–$9,575.1
2013	$1,387.46	$1,251.01	2.51%	–0.006%	$29,136.6	–$10,216.5
2014	$1,496.25	$1,329.31	2.52%	–0.006%	$32,268.0	–$12,715.2
2015	$1,418.49	$1,254.49	2.06%	–0.006%	$32,185.8	–$12,703.7
2016	$1,434.64	$1,277.00	2.24%	–0.006%	$32,218.8	–$12,414.3
2017	$1,426.31	$1,275.92	2.24%	–0.006%	$32,152.6	–$12,038.9
2018	$1,418.48	$1,274.87	2.24%	–0.006%	$32,104.6	–$11,681.6
2019	$1,412.32	$1,273.86	2.24%	–0.006%	$32,174.9	–$11,442.5
2020	$1,409.22	$1,272.88	2.24%	–0.006%	$32,485.8	–$11,444.0
2021	$1,362.03	$1,271.92	2.24%	–0.006%	$29,031.1	–$7,680.1
2022	$1,305.18	$1,270.99	2.25%	–0.006%	$24,618.3	–$2,958.0
2023	$1,297.20	$1,270.10	2.25%	–0.006%	$24,349.5	–$2,380.0
2024	$1,270.65	$1,269.22	2.25%	–0.006%	$22,405.9	–$127.2
2025	$1,269.80	$1,268.37	2.25%	–0.006%	$22,716.8	–$128.8
2026	$1,268.97	$1,267.55	2.25%	–0.006%	$23,027.6	–$130.4
2027	$1,268.17	$1,266.75	2.25%	–0.006%	$23,338.4	–$132.0
2028	$1,267.39	$1,265.97	2.25%	–0.006%	$23,649.3	–$133.6
2029	$1,266.63	$1,265.21	2.25%	–0.006%	$23,960.1	–$135.2
2030	$1,265.89	$1,264.47	2.26%	–0.006%	$24,271.0	–$136.8
NPV[b]			1.84%		$333,923.8	–$85,851.8

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10.B-7. Impacts on Lawn and Garden Equipment Market and Manufacturers (Average Price per Equipment = $12,394)[a]

	Lawn and Garden					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (10^3)**	**Change in Producer Surplus for Equipment Manufacturers (10^3)**
2007	–$0.01	–$0.08	0.00%	–0.002%	—	–$2.9
2008	$138.80	$120.56	3.07%	–0.002%	$2,233.4	–$760.0
2009	$138.46	$120.64	3.08%	–0.002%	$2,271.9	–$760.1
2010	$131.75	$114.32	2.92%	–0.003%	$2,228.9	–$760.9
2011	$168.43	$146.92	2.95%	–0.003%	$2,520.4	–$960.6
2012	$333.59	$299.74	3.23%	–0.005%	$3,435.9	–$1,545.1
2013	$574.91	$536.55	6.96%	–0.006%	$5,502.4	–$1,789.2
2014	$581.20	$539.53	6.96%	–0.006%	$5,774.8	–$1,984.8
2015	$454.05	$413.26	4.97%	–0.006%	$4,984.6	–$1,983.7
2016	$508.37	$468.39	5.91%	–0.006%	$5,470.2	–$1,984.3
2017	$506.56	$467.36	5.90%	–0.006%	$5,538.9	–$1,984.5
2018	$494.69	$466.36	5.90%	–0.006%	$5,085.3	–$1,462.3
2019	$493.20	$465.40	5.90%	–0.006%	$5,154.1	–$1,462.5
2020	$491.76	$464.48	5.90%	–0.006%	$5,222.8	–$1,462.7
2021	$486.74	$463.59	5.90%	–0.006%	$5,092.9	–$1,264.2
2022	$475.01	$462.74	5.90%	–0.006%	$4,579.5	–$682.3
2023	$465.57	$461.91	5.89%	–0.006%	$4,172.9	–$207.1
2024	$461.32	$461.11	5.89%	–0.006%	$4,046.5	–$12.1
2025	$460.55	$460.34	5.89%	–0.006%	$4,115.2	–$12.3
2026	$459.81	$459.60	5.89%	–0.006%	$4,183.9	–$12.4
2027	$459.09	$458.88	5.89%	–0.006%	$4,252.6	–$12.6
2028	$458.39	$458.18	5.89%	–0.006%	$4,321.4	–$12.8
2029	$457.71	$457.51	5.89%	–0.006%	$4,390.1	–$12.9
2030	$457.06	$456.85	5.88%	–0.006%	$4,458.8	–$13.1
NPV[b]			5.11%		$63,452.9	–$15,141.2

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

APPENDIX 10C: Impacts on Application Market Producers and Consumers

This appendix provides the time series of impacts from 2007 through 2030 for the product and service application markets included in the model. There are 3 application markets: construction, agriculture, and manufacturing.

Tables 10C-1 through 10C-3 provide the time series of impacts for the three application markets. Each table includes the following:

- relative change in market price (%),
- relative change in market quantity (%), and
- change in producer and consumer surplus for each application market.

Price increases range from an average of 0.01 percent in the manufacturing sector to 0.05 percent in the agricultural sector. Even though the cost per engine and market impacts (in terms of percentage change in price and quantity) stabilize in the later years of the regulation, the engineering costs and producer surplus changes continue to gradually increase because the projected consumption by producers and consumers within each application market increases over time.

Table 10C-1. Impacts on Agricultural Application Market and Agricultural Producers and Consumers[a]

	Agriculture		
Year	**Change in Price (%)**	**Change in Quantity (%)**	**Change in Producer and Consumer Surplus ($$10^3$)**
2007	0.009%	–0.002%	–$43,960.9
2008	0.012%	–0.002%	–$57,864.1
2009	0.012%	–0.002%	–$59,188.4
2010	0.021%	–0.004%	–$108,934.7
2011	0.044%	–0.009%	–$229,431.7
2012	0.059%	–0.012%	–$315,186.7
2013	0.064%	–0.013%	–$348,696.5
2014	0.068%	–0.014%	–$377,452.5
2015	0.063%	–0.013%	–$357,954.7
2016	0.065%	–0.013%	–$374,252.1
2017	0.065%	–0.013%	–$380,487.4
2018	0.065%	–0.013%	–$386,722.8
2019	0.065%	–0.013%	–$392,958.1
2020	0.065%	–0.013%	–$399,193.5
2021	0.065%	–0.013%	–$405,428.8
2022	0.065%	–0.013%	–$411,664.1
2023	0.065%	–0.013%	–$417,899.4
2024	0.065%	–0.013%	–$424,134.7
2025	0.065%	–0.013%	–$430,370.0
2026	0.065%	–0.013%	–$436,592.0
2027	0.065%	–0.013%	–$442,814.0
2028	0.065%	–0.013%	–$449,036.0
2029	0.065%	–0.013%	–$455,257.9
2030	0.065%	–0.013%	–$461,479.9
	AVG	AVG	NPV[b]
	0.055%	–0.011%	–$5,050,376.0

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10C-2. Impacts on Construction Application Market and Construction Producers and Consumers[a]

Year	Construction		Change in Producer and Consumer Surplus ($10^3)
	Change in Price (%)	Change in Quantity (%)	
2007	0.003%	–0.003%	–$58,654.6
2008	0.004%	–0.004%	–$74,356.5
2009	0.004%	–0.004%	–$76,058.2
2010	0.007%	–0.007%	–$143,107.9
2011	0.015%	–0.014%	–$297,490.6
2012	0.021%	–0.020%	–$437,573.1
2013	0.022%	–0.021%	–$468,250.1
2014	0.024%	–0.023%	–$515,649.1
2015	0.023%	–0.022%	–$499,896.0
2016	0.023%	–0.022%	–$516,309.7
2017	0.023%	–0.022%	–$524,842.8
2018	0.023%	–0.022%	–$533,375.9
2019	0.023%	–0.022%	–$541,909.0
2020	0.023%	–0.022%	–$550,442.1
2021	0.023%	–0.022%	–$558,975.1
2022	0.023%	–0.022%	–$567,508.0
2023	0.023%	–0.022%	–$576,041.0
2024	0.023%	–0.022%	–$584,573.9
2025	0.023%	–0.022%	–$593,106.8
2026	0.023%	–0.022%	–$601,622.0
2027	0.023%	–0.022%	–$610,137.1
2028	0.023%	–0.022%	–$618,652.2
2029	0.023%	–0.022%	–$627,167.4
2030	0.023%	–0.022%	–$635,682.5
	AVG	AVG	NPV[b]
	0.020%	–0.019%	–$6,923,515.6

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10C-3. Impacts on Manufacturing Application Market and Manufacturing Producers and Consumers[a]

Year	Manufacturing		Change in Producer and Consumer Surplus ($$10^3$)
	Change in Price (%)	Change in Quantity (%)	
2007	0.003%	–0.002%	–$111,732.2
2008	0.004%	–0.002%	–$148,130.8
2009	0.004%	–0.002%	–$150,298.2
2010	0.004%	–0.003%	–$181,349.6
2011	0.005%	–0.003%	–$222,767.7
2012	0.008%	–0.004%	–$316,540.3
2013	0.010%	–0.006%	–$414,805.7
2014	0.010%	–0.006%	–$428,962.5
2015	0.009%	–0.005%	–$388,563.0
2016	0.009%	–0.005%	–$412,018.5
2017	0.009%	–0.005%	–$418,249.7
2018	0.009%	–0.005%	–$424,459.7
2019	0.009%	–0.005%	–$430,700.7
2020	0.009%	–0.005%	–$436,821.7
2021	0.009%	–0.005%	–$443,264.9
2022	0.009%	–0.005%	–$449,719.9
2023	0.009%	–0.005%	–$456,187.1
2024	0.009%	–0.005%	–$462,666.7
2025	0.009%	–0.005%	–$469,158.8
2026	0.009%	–0.005%	–$475,656.2
2027	0.009%	–0.005%	–$482,166.5
2028	0.009%	–0.005%	–$488,690.2
2029	0.009%	–0.005%	–$495,227.3
2030	0.009%	–0.005%	–$501,778.2
	AVG	AVG	NPV[b]
	0.008%	–0.005%	–$5,770,293.9

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

APPENDIX 10D: Impacts on the Nonroad Fuel Market

This appendix provides the time series of impacts from 2007 through 2030 for the nonroad diesel fuel market. Eight nonroad diesel fuel markets were modeled: 2 sulfur content levels (15 ppm and 500 ppm) for each of 4 PADDs (PADDs 1&3, PADD 2, PADD 4, and PADD 5). It should be noted that PADD 5 includes Alaska and Hawaii.

Tables 10D-1 through 10D-4 provide the time series of impacts for the diesel fuel market for the four regional fuel markets. Each table includes the following:

- average price per gallon,
- average engineering costs (variable and fixed) per gallon,
- absolute change in the PADDs' nonroad diesel price ($),
  - Note that the estimated absolute change in market price is based on average variable and fixed costs; see Appendix I for sensitivity analyses reflecting maximum total costs and maximum variable costs
- relative change in the PADDs' nonroad diesel price (%),
- relative change in the PADDs' nonroad diesel quantity (%),
- total engineering (regulatory) costs associated with each PADD's fuel market ($), and
- change in producer surplus for all fuel producers.

About 60 to 65 percent of high-sulfur diesel fuel is consumed by nonroad diesel equipment, the other 35 to 40 percent is consumed by marine equipment and locomotive engines. The engineering costs and changes in producer surplus presented in this appendix include both of these diesel fuel segments.

All prices and costs are presented in $2001, and the real per-gallon prices are assumed to be constant within each regional fuel market. Initially, nonroad diesel equipment, locomotive, and marine engines are included in the 500 ppm market. As the proposed rule phases in 2010, nonroad equipment switches to the 15 ppm market. The engineering compliance costs are greater to refine 15 ppm (4.6 cents/gal) compared to 500 ppm (2.6 cents/gal), thus the price change in the 15 ppm market is greater than in the 500 ppm market.

For each regional fuel market, the majority of the cost of the regulation is passed along through increased fuel prices. Price increases for the 15 ppm market are about an average of 6.24 percent per gallon in each regional fuel market. Even though the cost per engine and market impacts (in terms of percentage change in price and quantity) stabilize within the first few years of the regulation, the engineering costs and producer surplus changes continue to gradually increase because the projected consumption of diesel fuel increases over time.

Table 10D-1. Impacts on the Nonroad Fuel Market in PADD 1&3 (Average Price per Gallon = $0.9199)[a]

	15ppm PADD 1&3					500ppm PADD 1&3					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs ($$10^6$)**	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs ($$10^6$)**	**Change in Producer Surplus for Fuel Producers ($$10^6$)**
2007		—	0.00%	0.000%	—	$0.0209	$0.02	1.64%	–0.002%	$69.8	–$0.4
2008		—	0.00%	0.000%	—	$0.0209	$0.02	1.64%	–0.003%	$71.1	–$0.5
2009		—	0.00%	0.000%	—	$0.0209	$0.02	1.64%	–0.003%	$72.4	–$0.6
2010	$0.0301	$0.03	3.25%	–0.006%	$97.9	$0.0159	$0.02	1.72%	–0.003%	$25.4	–$0.9
2011	$0.0301	$0.03	3.23%	–0.011%	$100.1	$0.0159	$0.02	1.71%	–0.003%	$25.8	–$1.6
2012	$0.0301	$0.03	3.21%	–0.016%	$102.2	$0.0159	$0.02	1.71%	–0.005%	$26.0	–$2.4
2013	$0.0301	$0.03	3.20%	–0.017%	$104.4	$0.0159	$0.02	1.70%	–0.006%	$26.1	–$2.7
2014	$0.0301	$0.03	3.20%	–0.018%	$106.6	$0.0159	$0.02	1.70%	–0.006%	$26.3	–$2.9
2015	$0.0301	$0.03	3.20%	–0.017%	$108.8	$0.0159	$0.02	1.70%	–0.006%	$26.5	–$2.8
2016	$0.0301	$0.03	3.20%	–0.018%	$111.0	$0.0159	$0.02	1.70%	–0.006%	$26.8	–$2.9
2017	$0.0301	$0.03	3.20%	–0.018%	$113.1	$0.0159	$0.02	1.70%	–0.006%	$27.0	–$2.9
2018	$0.0301	$0.03	3.20%	–0.018%	$115.3	$0.0159	$0.02	1.70%	–0.006%	$27.2	–$3.0
2019	$0.0301	$0.03	3.20%	–0.018%	$117.4	$0.0159	$0.02	1.70%	–0.006%	$27.4	–$3.0
2020	$0.0301	$0.03	3.20%	–0.018%	$119.6	$0.0159	$0.02	1.70%	–0.006%	$27.6	–$3.1
2021	$0.0301	$0.03	3.20%	–0.018%	$121.8	$0.0159	$0.02	1.70%	–0.006%	$27.9	–$3.1
2022	$0.0301	$0.03	3.20%	–0.018%	$123.9	$0.0159	$0.02	1.70%	–0.006%	$28.2	–$3.2
2023	$0.0301	$0.03	3.20%	–0.018%	$126.1	$0.0159	$0.02	1.70%	–0.006%	$28.4	–$3.2
2024	$0.0301	$0.03	3.20%	–0.018%	$128.3	$0.0159	$0.02	1.70%	–0.006%	$28.7	–$3.3
2025	$0.0301	$0.03	3.20%	–0.018%	$130.4	$0.0159	$0.02	1.70%	–0.006%	$29.0	–$3.3
2026	$0.0301	$0.03	3.20%	–0.018%	$132.6	$0.0159	$0.02	1.70%	–0.006%	$29.3	–$3.4
2027	$0.0301	$0.03	3.20%	–0.018%	$134.7	$0.0159	$0.02	1.70%	–0.006%	$29.6	–$3.4
2028	$0.0301	$0.03	3.20%	–0.018%	$136.9	$0.0159	$0.02	1.70%	–0.006%	$29.9	–$3.5
2029	$0.0301	$0.03	3.20%	–0.018%	$139.0	$0.0159	$0.02	1.70%	–0.006%	$30.2	–$3.5
2030	$0.0301	$0.03	3.20%	–0.018%	$141.2	$0.0159	$0.02	1.70%	–0.006%	$30.5	–$3.6
NPV[b]			2.802%		$1,559.2			1.697%		$555.7	–$39.0

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10D-2. Impacts on the Nonroad Fuel Market in PADD 2 (Average Price per Gallon = $0.9399)[a]

	15ppm PADD 2					500ppm PADD 2					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (\$$10^6$)**	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs (\$$10^6$)**	**Change in Producer Surplus for Fuel Producers (\$$10^6$)**
2007		—	0.00%	0.000%	—	$0.0415	$0.03	3.19%	–0.002%	$96.6	–$0.3
2008		—	0.00%	0.000%	—	$0.0415	$0.03	3.19%	–0.003%	$98.3	–$0.4
2009		—	0.00%	0.000%	—	$0.0415	$0.03	3.19%	–0.003%	$100.1	–$0.4
2010	$0.0611	$0.06	6.48%	–0.006%	$132.8	$0.0357	$0.04	3.79%	–0.003%	$43.2	–$0.6
2011	$0.0611	$0.06	6.45%	–0.012%	$135.7	$0.0357	$0.04	3.78%	–0.003%	$43.9	–$1.2
2012	$0.0611	$0.06	6.43%	–0.016%	$138.7	$0.0357	$0.04	3.78%	–0.005%	$44.2	–$1.7
2013	$0.0611	$0.06	6.43%	–0.018%	$141.7	$0.0357	$0.04	3.77%	–0.006%	$44.5	–$1.9
2014	$0.0611	$0.06	6.42%	–0.019%	$144.6	$0.0357	$0.04	3.77%	–0.006%	$44.7	–$2.1
2015	$0.0611	$0.06	6.43%	–0.018%	$147.6	$0.0357	$0.04	3.77%	–0.006%	$45.1	–$1.9
2016	$0.0611	$0.06	6.43%	–0.018%	$150.5	$0.0357	$0.04	3.77%	–0.006%	$45.5	–$2.0
2017	$0.0611	$0.06	6.43%	–0.018%	$153.4	$0.0357	$0.04	3.77%	–0.006%	$45.9	–$2.1
2018	$0.0611	$0.06	6.43%	–0.018%	$156.4	$0.0357	$0.04	3.77%	–0.006%	$46.3	–$2.1
2019	$0.0611	$0.06	6.43%	–0.018%	$159.3	$0.0357	$0.04	3.77%	–0.006%	$46.7	–$2.1
2020	$0.0611	$0.06	6.43%	–0.018%	$162.3	$0.0357	$0.04	3.77%	–0.006%	$47.0	–$2.2
2021	$0.0611	$0.06	6.43%	–0.018%	$165.2	$0.0357	$0.04	3.77%	–0.006%	$47.4	–$2.2
2022	$0.0611	$0.06	6.43%	–0.018%	$168.1	$0.0357	$0.04	3.77%	–0.006%	$47.9	–$2.2
2023	$0.0611	$0.06	6.43%	–0.018%	$171.1	$0.0357	$0.04	3.77%	–0.006%	$48.4	–$2.3
2024	$0.0611	$0.06	6.43%	–0.018%	$174.0	$0.0357	$0.04	3.77%	–0.006%	$48.9	–$2.3
2025	$0.0611	$0.06	6.43%	–0.018%	$176.9	$0.0357	$0.04	3.77%	–0.006%	$49.4	–$2.4
2026	$0.0611	$0.06	6.43%	–0.018%	$179.8	$0.0357	$0.04	3.77%	–0.006%	$49.9	–$2.4
2027	$0.0611	$0.06	6.43%	–0.018%	$182.8	$0.0357	$0.04	3.77%	–0.006%	$50.4	–$2.4
2028	$0.0611	$0.06	6.43%	–0.018%	$185.7	$0.0357	$0.04	3.77%	–0.006%	$50.9	–$2.5
2029	$0.0611	$0.06	6.43%	–0.018%	$188.6	$0.0357	$0.04	3.77%	–0.006%	$51.4	–$2.5
2030	$0.0611	$0.06	6.43%	–0.018%	$191.5	$0.0357	$0.04	3.77%	–0.006%	$51.9	–$2.5
NPV[b]			5.626%		$2,115.0			3.702%		$885.1	–$27.7

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10D-3. Impacts on the Nonroad Fuel Market in PADD 4 (Average Price per Gallon = $0.9499)[a]

	15ppm PADD 4					500ppm PADD 4					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs ($\$10^6$)**	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs ($\$10^6$)**	**Change in Producer Surplus for Fuel Producers ($\$10^6$)**
2007		—	0.00%	0.000%	—	$0.0371	$0.04	4.33%	–0.002%	$34.0	–$0.1
2008		—	0.00%	0.000%	—	$0.0371	$0.04	4.33%	–0.003%	$34.4	–$0.1
2009		—	0.00%	0.000%	—	$0.0371	$0.04	4.33%	–0.003%	$34.9	–$0.1
2010	$0.0891	$0.09	9.35%	–0.006%	$25.3	$0.0336	$0.03	3.52%	–0.003%	$19.3	–$0.1
2011	$0.0891	$0.09	9.33%	–0.012%	$25.9	$0.0336	$0.03	3.52%	–0.003%	$19.5	–$0.2
2012	$0.0891	$0.09	9.31%	–0.017%	$26.4	$0.0336	$0.03	3.52%	–0.005%	$19.7	–$0.3
2013	$0.0891	$0.09	9.30%	–0.018%	$27.0	$0.0336	$0.03	3.51%	–0.006%	$19.8	–$0.4
2014	$0.0891	$0.09	9.30%	–0.020%	$27.6	$0.0336	$0.03	3.51%	–0.006%	$19.9	–$0.4
2015	$0.0891	$0.09	9.30%	–0.019%	$28.1	$0.0336	$0.03	3.51%	–0.006%	$20.1	–$0.4
2016	$0.0891	$0.09	9.30%	–0.019%	$28.7	$0.0336	$0.03	3.51%	–0.006%	$20.3	–$0.4
2017	$0.0891	$0.09	9.30%	–0.019%	$29.2	$0.0336	$0.03	3.51%	–0.006%	$20.5	–$0.4
2018	$0.0891	$0.09	9.30%	–0.019%	$29.8	$0.0336	$0.03	3.51%	–0.006%	$20.6	–$0.4
2019	$0.0891	$0.09	9.30%	–0.019%	$30.4	$0.0336	$0.03	3.51%	–0.006%	$20.8	–$0.4
2020	$0.0891	$0.09	9.30%	–0.019%	$30.9	$0.0336	$0.03	3.51%	–0.006%	$20.9	–$0.4
2021	$0.0891	$0.09	9.30%	–0.019%	$31.5	$0.0336	$0.03	3.51%	–0.006%	$21.1	–$0.4
2022	$0.0891	$0.09	9.30%	–0.019%	$32.0	$0.0336	$0.03	3.51%	–0.006%	$21.4	–$0.4
2023	$0.0891	$0.09	9.30%	–0.019%	$32.6	$0.0336	$0.03	3.51%	–0.006%	$21.6	–$0.4
2024	$0.0891	$0.09	9.30%	–0.019%	$33.2	$0.0336	$0.03	3.51%	–0.006%	$21.8	–$0.4
2025	$0.0891	$0.09	9.30%	–0.019%	$33.7	$0.0336	$0.03	3.51%	–0.006%	$22.0	–$0.4
2026	$0.0891	$0.09	9.30%	–0.019%	$34.3	$0.0336	$0.03	3.51%	–0.006%	$22.2	–$0.4
2027	$0.0891	$0.09	9.30%	–0.019%	$34.8	$0.0336	$0.03	3.51%	–0.006%	$22.5	–$0.4
2028	$0.0891	$0.09	9.30%	–0.019%	$35.4	$0.0336	$0.03	3.51%	–0.006%	$22.7	–$0.5
2029	$0.0891	$0.09	9.30%	–0.019%	$35.9	$0.0336	$0.03	3.51%	–0.006%	$22.9	–$0.5
2030	$0.0891	$0.09	9.30%	–0.019%	$36.5	$0.0336	$0.03	3.51%	–0.006%	$23.1	–$0.5
NPV[b]			8.142%		$403.0			3.615%		$369.3	–$5.2

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

Table 10D-4. Impacts on the Nonroad Fuel Market in PADD 5 (Average Price per Gallon = $0.9599)[a]

	15ppm PADD 5					500ppm PADD 5					
Year	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs ($\$10^6$)**	**Engineering Cost/Unit**	**Absolute Change in Price**	**Change in Price (%)**	**Change in Quantity (%)**	**Total Engineering Costs ($\$10^6$)**	**Change in Producer Surplus for Fuel Producers ($\$10^6$)**
2007		—	0.00%	0.000%	—	$0.0344	$0.03	2.64%	–0.002%	$15.7	–$0.1
2008		—	0.00%	0.000%	—	$0.0344	$0.03	2.63%	–0.003%	$16.0	–$0.1
2009		—	0.00%	0.000%	—	$0.0344	$0.03	2.63%	–0.003%	$16.3	–$0.1
2010	$0.0586	$0.06	6.08%	–0.006%	$27.3	$0.0217	$0.02	2.25%	–0.003%	$4.1	–$0.1
2011	$0.0586	$0.06	6.06%	–0.012%	$27.9	$0.0217	$0.02	2.25%	–0.003%	$4.1	–$0.3
2012	$0.0586	$0.06	6.03%	–0.017%	$28.5	$0.0217	$0.02	2.24%	–0.005%	$4.2	–$0.4
2013	$0.0586	$0.06	6.03%	–0.018%	$29.1	$0.0217	$0.02	2.23%	–0.006%	$4.2	–$0.4
2014	$0.0586	$0.06	6.02%	–0.019%	$29.7	$0.0217	$0.02	2.23%	–0.006%	$4.2	–$0.4
2015	$0.0586	$0.06	6.03%	–0.018%	$30.3	$0.0217	$0.02	2.24%	–0.006%	$4.2	–$0.4
2016	$0.0586	$0.06	6.03%	–0.019%	$30.9	$0.0217	$0.02	2.24%	–0.006%	$4.3	–$0.4
2017	$0.0586	$0.06	6.03%	–0.019%	$31.5	$0.0217	$0.02	2.24%	–0.006%	$4.3	–$0.4
2018	$0.0586	$0.06	6.03%	–0.019%	$32.1	$0.0217	$0.02	2.24%	–0.006%	$4.4	–$0.5
2019	$0.0586	$0.06	6.03%	–0.019%	$32.7	$0.0217	$0.02	2.24%	–0.006%	$4.4	–$0.5
2020	$0.0586	$0.06	6.03%	–0.019%	$33.3	$0.0217	$0.02	2.24%	–0.006%	$4.4	–$0.5
2021	$0.0586	$0.06	6.03%	–0.019%	$33.9	$0.0217	$0.02	2.24%	–0.006%	$4.5	–$0.5
2022	$0.0586	$0.06	6.03%	–0.019%	$34.5	$0.0217	$0.02	2.24%	–0.006%	$4.5	–$0.5
2023	$0.0586	$0.06	6.03%	–0.019%	$35.1	$0.0217	$0.02	2.24%	–0.006%	$4.6	–$0.5
2024	$0.0586	$0.06	6.03%	–0.019%	$35.7	$0.0217	$0.02	2.24%	–0.006%	$4.6	–$0.5
2025	$0.0586	$0.06	6.03%	–0.019%	$36.3	$0.0217	$0.02	2.24%	–0.006%	$4.6	–$0.5
2026	$0.0586	$0.06	6.03%	–0.019%	$36.9	$0.0217	$0.02	2.24%	–0.006%	$4.7	–$0.5
2027	$0.0586	$0.06	6.03%	–0.019%	$37.5	$0.0217	$0.02	2.24%	–0.006%	$4.7	–$0.5
2028	$0.0586	$0.06	6.03%	–0.019%	$38.1	$0.0217	$0.02	2.24%	–0.006%	$4.8	–$0.5
2029	$0.0586	$0.06	6.03%	–0.019%	$38.7	$0.0217	$0.02	2.24%	–0.006%	$4.8	–$0.5
2030	$0.0586	$0.06	6.03%	–0.018%	$39.3	$0.0217	$0.02	2.24%	–0.006%	$4.9	–$0.5
NPV[b]			5.278%		$434.3			2.287%		$101.1	–$6.0

[a] Figures are in 2001 dollars.

[b] Net present values are calculated using a social discount rate of 3 percent over the 2004 to 2030 time period.

APPENDIX 10E: Time Series of Social Cost

This appendix provides a time series of the estimated social costs for the proposed program for the period 2007 through 2030. Costs are presented in 2001 dollars.

Table 10E-1. Time Series of Market Impacts

	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Engine Producers Total	$0.0	$14.0	$14.0	$14.0	$23.5	$29.4	$30.2	$35.6	$35.6	$25.5	$20.3	$5.5
Equipment Producers Total	$0.5	$8.9	$9.0	$9.5	$73.0	$106.2	$116.1	$144.0	$143.8	$124.9	$119.8	$111.3
Construction Equipment	$0.4	$2.0	$2.0	$2.4	$35.1	$50.1	$53.0	$67.8	$67.7	$57.5	$54.9	$53.2
Agricultural Equipment	$0.1	$2.4	$2.4	$2.6	$27.7	$37.0	$39.9	$49.2	$49.1	$41.0	$39.1	$36.5
Industrial Equipment	$0.1	$4.5	$4.5	$4.6	$10.2	$19.0	$23.2	$27.1	$27.0	$26.4	$25.8	$21.7
Application Producers & Consumers Total	$214.3	$280.4	$285.5	$433.4	$749.7	$1,069.3	$1,231.8	$1,322.1	$1,246.4	$1,302.6	$1,323.6	$1,344.6
Total Producer	*$86.7*	*$113.0*	*$115.2*	*$178.6*	*$315.7*	*$451.7*	*$515.7*	*$555.1*	*$525.1*	*$548.0*	*$556.9*	*$565.7*
Total Consumer	*$127.7*	*$167.3*	*$170.4*	*$254.8*	*$434.0*	*$617.6*	*$716.1*	*$767.0*	*$721.3*	*$754.6*	*$766.7*	*$778.8*
Construction	$58.7	$74.4	$76.1	$143.1	$297.5	$437.6	$468.3	$515.6	$499.9	$516.3	$524.8	$533.4
Agriculture	$44.0	$57.9	$59.2	$108.9	$229.4	$315.2	$348.7	$377.5	$358.0	$374.3	$380.5	$386.7
Manufacturing	$111.7	$148.1	$150.3	$181.3	$222.8	$316.5	$414.8	$429.0	$388.6	$412.0	$418.2	$424.5
Fuel Producers Total	$1.2	$1.5	$1.6	$2.6	$4.8	$6.9	$7.8	$8.4	$8.0	$8.4	$8.5	$8.7
PADD 1&3	$0.5	$0.7	$0.7	$1.2	$2.2	$3.2	$3.6	$3.9	$3.7	$3.9	$3.9	$4.0
PADD 2	$0.4	$0.6	$0.6	$0.9	$1.8	$2.6	$2.9	$3.1	$2.9	$3.1	$3.1	$3.2
PADD 4	$0.1	$0.2	$0.2	$0.3	$0.5	$0.7	$0.8	$0.9	$0.8	$0.8	$0.9	$0.9
PADD 5	$0.1	$0.1	$0.1	$0.2	$0.3	$0.5	$0.5	$0.6	$0.6	$0.6	$0.6	$0.6
Change in Market Surplus ($$10^6$/yr)	$216.1	$304.8	$310.0	$459.5	$851.0	$1,211.8	$1,385.8	$1,510.1	$1,433.9	$1,461.4	$1,472.2	$1,470.1
NR Spillover	$44.8	$45.8	$46.9	$48.0	$49.0	$50.1	$51.2	$52.3	$53.3	$54.4	$55.5	$56.5
Operating and Marker Costs ($$10^6$/yr)	–$221.3	–$220.3	–$224.7	–$245.5	–$259.0	–$251.6	–$234.6	–$233.4	–$226.6	–$217.5	–$209.0	–$201.7
Social Costs ($$10^6$/yr)	$39.6	$130.4	$132.2	$262.00	$641.1	$1,010.3	$1,202.4	$1,329.0	$1,260.6	$1,298.3	$1,318.6	$1,324.9

(continued)

Table 10E-1. Time Series of Market Impacts (continued)

	2019	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Engine Producers Total	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1
Equipment Producers Total	$102.6	$102.6	$60.3	$32.9	$23.6	$4.9	$5.0	$5.1	$5.1	$5.2	$5.3	$5.3
Construction Equipment	$48.2	$48.2	$27.4	$15.3	$12.9	$3.5	$3.6	$3.6	$3.7	$3.7	$3.8	$3.8
Agricultural Equipment	$33.2	$33.2	$17.0	$9.5	$7.1	$1.2	$1.2	$1.2	$1.3	$1.3	$1.3	$1.3
Industrial Equipment	$21.2	$21.2	$16.0	$8.1	$3.6	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2
Application Producers & Consumers Total	$1,365.6	$1,386.5	$1,407.7	$1,428.9	$1,450.1	$1,471.4	$1,492.6	$1,513.9	$1,535.1	$1,556.4	$1,577.7	$1,598.9
Total Producer	*$574.6*	*$583.4*	*$592.3*	*$601.3*	*$610.2*	*$619.2*	*$628.2*	*$637.1*	*$646.1*	*$655.1*	*$664.0*	*$672.9*
Total Consumer	*$791.0*	*$803.1*	*$815.3*	*$827.6*	*$839.9*	*$852.2*	*$864.5*	*$876.8*	*$889.1*	*$901.4*	*$913.7*	*$926.0*
Construction	$541.9	$550.4	$559.0	$567.5	$576.0	$584.6	$593.1	$601.6	$610.1	$618.7	$627.2	$635.7
Agriculture	$393.0	$399.2	$405.4	$411.7	$417.9	$424.1	$430.4	$436.6	$442.8	$449.0	$455.3	$461.5
Manufacturing	$430.7	$436.8	$443.3	$449.7	$456.2	$462.7	$469.2	$475.7	$482.2	$488.7	$495.2	$501.8
Fuel Producers Total	$8.8	$9.0	$9.1	$9.3	$9.4	$9.6	$9.7	$9.9	$10.0	$10.2	$10.3	$10.5
PADD 1&3	$4.1	$4.1	$4.2	$4.3	$4.3	$4.4	$4.5	$4.5	$4.6	$4.7	$4.7	$4.8
PADD 2	$3.2	$3.3	$3.4	$3.4	$3.5	$3.5	$3.6	$3.6	$3.7	$3.7	$3.8	$3.9
PADD 4	$0.9	$0.9	$0.9	$0.9	$0.9	$1.0	$1.0	$1.0	$1.0	$1.0	$1.0	$1.0
PADD 5	$0.6	$0.6	$0.7	$0.7	$0.7	$0.7	$0.7	$0.7	$0.7	$0.7	$0.7	$0.8
Change in Market Surplus ($\$10^6$/yr)	$1,477.1	$1,498.2	$1,477.2	$1,471.2	$1,483.3	$1,486.0	$1,507.5	$1,528.9	$1,550.4	$1,571.9	$1,593.4	$1,614.9
NR Spillover	$57.6	$58.6	$59.7	$60.8	$61.8	$62.9	$63.9	$65.0	$66.0	$67.1	$68.1	$69.2
Operating and Marker Costs ($\$10^6$/yr)	–$195.5	–$190.1	–$185.9	–$182.5	–$179.7	–$177.4	–$175.6	–$174.3	–$173.7	–$173.7	–$174.0	–$174.5
Social Costs ($\$10^6$/yr)	$1,339.2	$1,366.7	$1,350.9	$1,349.4	$1,365.4	$1,371.5	$1,395.8	$1,419.6	$1,442.8	$1,465.3	$1,487.5	$1,509.6

APPENDIX 10F: Model Equations

To enhance understanding of the economic model EPA used in this report, additional details about the model's structure are provided in this appendix. The equations describing supply, final demand, and intermediate (i.e., derived) demand relationships are presented below along with a brief description of the solution algorithm.

10F.1 Model Equations

A constant-elasticity functional form was selected for all supply and final demand functions. The general form and description of these equations are presented below:

$$\text{Supply Equation: } Q_x = a(P_x - \Delta c - \Delta c_y)^{\varepsilon} \qquad \text{(10F.1)}$$

$$\text{Final Demand Equation: } Q_x = aP_x^{\eta} \qquad \text{(10F.2)}$$

where

x = production output,
y = production input,
Q_x = quantity of output (x) supplied or demanded,
P_x = market price for output (x),
a = constant,
Δc = direct supply shift ($\$/Q_x$),
Δc_y = indirect supply shift resulting from change in the price of input y, and
ε,η = these parameters can be interpreted as the own-price elasticity of supply/demand for the economic agent (see Tables 10.3-12 and 10.3-13 for values of these parameters).

With this choice of functional form, the supply and demand elasticities are assumed to remain constant over the range of output affected by the regulation. This can be demonstrated by applying the definition of own-price elasticity of demand:

$$\frac{dq}{dp} \bullet \frac{p}{q} = Eap^{(1-\varepsilon)} \bullet \frac{p^{(1-\varepsilon)}}{a} = \varepsilon . \qquad \text{(10F.3)}$$

The intermediate input (Q_y) demands is specified within the supply chain as a function of output (Q_x). The subscript "0" denotes baseline and the subscript "1" denotes with regulation.

$$\text{Derived Demand Equation: } \quad Q_y = f(Q_x) \qquad \text{(10F.4a)}$$

$$Q_{y1} = Q_{y0}(1+\Delta Q_x/Q_x) \qquad \text{(10F.4b)}$$

Computing Supply/Demand Function Constants. Using the baseline price, quantity, and elasticity parameter, the value of the constants can be computed. For example, supply function constants can be calculated as follows:

$$\text{Constant Calibration: } a = \frac{Q_{x0}}{(P_{x0})^{\varepsilon}} \qquad (10F.5)$$

Direct Supply Shift (Dc). The direct upward shift in the supply function is calculated by using the annualized compliance cost estimates provided by the engineering cost analysis. Computing the supply shift in this manner treats the compliance costs as the conceptual equivalent of a unit tax on output.

Indirect Supply Shift (Dc_y). The indirect upward shift in the supply function is calculated by using the change in input (y) prices (i.e., engines, equipment, and/or fuel) that result from the direct compliance costs introduced into the model. Only two types of suppliers are affected by these changes: equipment producers that use diesel engines and application markets that use equipment with diesel engines and diesel fuel. The term Dc_y is computed as follows:

$$\Delta c_y = \frac{\Delta P_y \bullet Q_{y0}}{Q_{x0}}. \qquad (10F.6)$$

10F.2 Engine Markets

As described in Section 10.3.3.1, seven separate engine markets were modeled segmented by engine size in horsepower (the EIA includes more horsepower categories than the standards, allowing more efficient use of the engine compliance cost estimates developed for this proposal):

- less than 25 hp,
- 26 to 50 hp,
- 51 to 75 hp,
- 76 to 100 hp,
- 101 to 175 hp,
- 176 to 600 hp, and
- greater than 601 hp.

In each of these engine markets, there are three types of suppliers: captive suppliers (engines are consumed internally by integrated equipment manufacturers), merchant suppliers (engines are sold on the open market), and foreign suppliers. These supply segments are represented by upward-sloping supply functions. On the demand side, consumers of engines include integrated and nonintegrated equipment manufacturers[L] and are represented by derived demand functions (Eqs. [104a] and [10F.4b]).

$$\text{Captive Domestic Supply Equation:} \quad S_{engcap} = a_1(p - c)^{\varepsilon} \qquad (10F.7)$$

$$\text{Merchant Domestic Supply Equation:} \quad S_{engmer} = a_2(p - c)^{\varepsilon} \qquad (10F.8)$$

[L] Note that engines sold to foreign equipment manufacturers are not included in the domestic engine market because they are subject to different (foreign) environmental regulations and hence are considered different products.

Import Supply Equation: $M_{eng} = a(p - c)^{\varepsilon}$ (10F.9)
Integrated Demand Equation: $D_I = S\,(S_{equip})$ (10F.10)
Nonintegrated Demand Equation: $D_{NI} = S(S_{equip})$ (10F.11)
Market Clearing Condition: $S_{engcap} + S_{engmer} + M_{eng} = D_I + D_{NI}$ (10F.12)

10F.3 Equipment Markets

As described in Section 10.3.3.2, integrated and nonintegrated equipment manufacturers supply their products into a series of 42 equipment markets (7 horsepower categories within 7 application categories; there are 7 horsepower/application categories that did not have sales in 2000 and are not included in the model,[M] so the total number of diesel equipment markets is 42, not 49). The equipment types are:

- construction
- agricultural,
- refrigeration
- generators and welder sets
- lawn and garden
- pumps and compressors
- general industrial

Each individual equipment market is comprised of two aggregate suppliers groups:
(1) domestic integrated suppliers that produce and consume their own engines (captive engines) and (2) domestic nonintegrated suppliers that purchase engines from the open market to be used in their equipment (merchant engines).

On the demand side, each of the 42 equipment markets is linked to one of three application markets (construction, agricultural, and manufacturers) is represented by derived demand functions (Eq. [10F.4a and 10F.4b])

Domestic Integrated Supply Equation: $S_{eqI} = a(p - c)^{\varepsilon}$ (10F.13)
Domestic Nonintegrated Supply Equation: $S_{eqNI} = a(p - c - c_y)^{\varepsilon}$ (10F.14)
Domestic Demand Equation: $D_{eq} = \sum Q_{eq}\left(1 + \frac{\Delta Q_{qpp}}{Q_{qpp0}}\right)$ (10F.15)
Market Clearing Condition: $S_{eqI} + S_{eqNI} = D_{eq}$ (10F.16)

10F.4 Application Markets

As described in Section 10.3.3.3, there are three application markets that supply products and services to consumers:

[M] These are: agricultural equipment >600 hp; gensets & welders > 600 hp; refrigeration & A/C > 71 hp (4 hp categories); and lawn & garden >600 hp.

- construction
- agricultural, and
- manufacturing.

The supply in each of these three application markets is the sum of a domestic supply and an foreign (import) supply. The consumers in the application markets are represented by a domestic demand and a foreign (export) demand function.

Supply Equation: $S_{app} = a(p_{app} - \beta_0 \Delta \mathbf{P}_{eq} - \beta_1 \Delta p_{fuel})^{\varepsilon}$ (10F.17)

Foreign (Import) Supply Equation: $M_{app} = ap_{app}\varepsilon$ (10F.18)

Domestic Demand Equation: $D_{app} = ap^{\eta}$ (10F.19)

Foreign (Export) Demand Equation: $X_{app} = ap^{\eta}$ (10F.20)

Market Clearing Condition: $S_{app} + M_{app} = D_{app} + X_{app}$ (10F.21)

β_0 and β_1 are the baseline input shares of equipment $\left(\frac{Q_{eq0}}{Q_{app0}}\right)$ and fuel $\left(\frac{Q_{fuel0}}{Q_{app0}}\right)$.

10F.5 Fuel Markets

As described in Section 10.3.3.4, eight nonroad diesel fuel markets were modeled: two distinct nonroad diesel fuel commodities in four regional markets. The two fuels are:

- 500 ppm nonroad diesel fuel, and
- 15 ppm nonroad diesel fuel.

The four regional nonroad diesel fuel markets are

- PADD 1 and 3,
- PADD 2,
- PADD 4, and
- PADD 5 (includes Alaska and Hawaii)

The supply and demand for nonroad diesel fuel is specified for the model for four regional diesel fuel markets. Derived demand of diesel fuel comes from three application markets. The equations for PADD district j are specified below:

Supply Equation: $S_j = a(P_j - \Delta c)\varepsilon$ (10F.22)

Derived Demand Equation: $D_j = \Sigma Q_{j0}\left(1 + \frac{\Delta Q_{app}}{Q_{app0}}\right)$ (10F.23)

Market Clearing Condition: $S_j = D_j$ (10F.24)

10F.6 Market-Clearing Process and Equations

Supply responses and market adjustments can be conceptualized as an interactive process. Producers facing increased production costs due to compliance with the control program are willing to supply smaller quantities at the baseline price. This reduction in market supply leads to an increase in the market price that all producers and consumers face, which leads to further responses by producers and consumers and thus new market prices, and so on. The new with-regulation equilibrium is the result of a series of iterations in which price is adjusted and producers and consumers respond, until a set of stable market prices arises where total market supply equals market demand.

$$\text{Market-Clearing Equation: Total Supply = Total Demand.} \qquad (10F.25)$$

The algorithm for determining with-regulation equilibria can be summarized by six recursive steps:

1. Impose the control costs on affected supply segments, thereby affecting their supply decisions.
2. Recalculate the market supply in each market. Excess demand currently exists.
3. Determine the new prices via a price revision rule. A rule similar to the factor price revision rule described by Kimbell and Harrison (1986) is used. P_i is the market price at iteration i, q_d is the quantity demanded, and q_s is the quantity supplied. The parameter z influences the magnitude of the price revision and speed of convergence. The revision rule increases the price when excess demand exists, lowers the price when excess supply exists, and leaves the price unchanged when market demand equals market supply. The price adjustment is expressed as follows:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s} \right)^z \qquad (10F.26)$$

4. Recalculate market supply with new prices, accounting for fuel-switching choices associated with new energy prices.
5. Compute market demand in each market.
6. Compare supply and demand in each market. If equilibrium conditions are not satisfied, go to Step 3, resulting in a new set of market prices. Repeat until equilibrium conditions are satisfied (i.e., the ratio of supply and demand is arbitrarily close to one).

APPENDIX 10G: Elasticity Parameters for Economic Impact Modeling

The Nonroad Diesel Economic Impact Model (NDEIM) relies on elasticity parameters to estimate the behavioral response of consumers and producers to the implementation of the proposed rule and its associated costs. To operationalize the market model, supply and demand elasticities are needed to represent the behavioral adjustments that are likely to be made by market participants. The following parameters are needed:

- supply and demand elasticities for application markets (construction, agriculture, and manufacturing),
- supply elasticities for equipment markets,
- supply elasticities for engine markets, and
- supply elasticities for diesel fuel markets.

Note that demand elasticities for the equipment, engine, and diesel fuel markets are not estimated because they are derived internally in the model. They are a function of changes in output levels in the applications markets.

Tables 10G-1 and 10G-2 contains the demand and supply elasticities used to estimate the economic impact of the proposed rule. Two methods were used to obtain the supply and demand elasticities used in the NDEIM. First, the professional literature was surveyed to identify elasticity estimates used in published studies. Second, when literature estimates were not available for specific markets, established econometric techniques were used to estimate supply and demand elasticity parameters directly. Specifically, the supply elasticities for the construction and agricultural application markets and the supply elasticity for the diesel fuel market were obtained from the literature. The supply elasticity for the manufacturing market is assumed to be the same as for the construction market. The supply elasticities for all of the application markets and for equipment and engine markets were estimated econometrically.

This appendix discusses the literature for elasticities based on existing studies and presents the data sources and estimation methodology and regression results for the econometric estimation.

Finally, it should be noted that these elasticities reflect intermediate run behavioral changes. In the long run, supply and demand are expected to be more elastic since more substitutes may become available.

Table 10G-1
Summary of Market Demand Elasticities Used in the NDEIM

Market	Estimate	Source	Method	Input Data Summary
Applications				
Construction	–0.96	EPA econometric estimate	Simultaneous equation (log-log) approach	Annual time series from 1958 – 1995 developed by Jorgenson et al. (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987)
Agriculture	–0.20	EPA econometric estimate	Productivity shift approach (Morgenstern, Pizer, and Shih, 2002)	Annual time series from 1958 – 1995 developed by Jorgenson et al. (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987)
Manufacturing	–0.58	EPA econometric estimate	Simultaneous equation (log-log) approach.	Annual time series from 1958 – 1995 developed by Jorgenson et al. (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987)
Equipment				
Construction		Derived demand	In the derived demand approach, • compliance costs increase prices and decrease demand for products and services in the application markets; • this in turn leads to reduced demand for diesel equipment, engines and fuel, which are inputs into the production of products and services in the application markets	
Agriculture		Derived demand		
Pumps/ compressors		Derived demand		
Generators and Welders		Derived demand		
Refrigeration		Derived demand		
Industrial		Derived demand		
Lawn and Garden		Derived demand		
Engines		Derived demand		
Diesel fuel		Derived demand		

Table 10G-2
Summary of Market Supply Elasticities Used in the NDEIM

Markets	Estimate	Source	Method	Input Data Summary
Applications				
Construction	1.0	Literature-based estimate	Based on Topel and Rosen, (1988).[a]	Census data, 1963 – 1983
Agriculture	0.32	Literature-based estimate	Production-weighted average of individual crop estimates ranging from 0.27 to 0.55. (Lin et al., 2000)	Agricultural Census data 1991 – 1995
Manufacturing	1.0	Literature-based estimate	Literature estimates are not available so assumed same value as for Construction market	Not applicable
Equipment				
Construction	3.31	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3531
Agriculture	2.14	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3523
Pumps/ compressors	2.83	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3561 and 3563
Generators/ Welder Sets	2.91	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3548
Refrigeration	2.83	EPA econometric estimate		Assumed same as pumps/compressors
Industrial	5.37	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3537
Lawn and Garden	3.37	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3524
Engines	3.81	EPA econometric estimate	Cobb-Douglas production function	Census data 1958-1996; SIC 3519
Diesel fuel	0.24	Literature based estimate	Based on Considine (2002).[b]	From Energy Intelligence Group (EIG); 1987-2000

[a] Most other studies estimate ranges that encompass 1.0, including DiPasquale (1997) and DiPasquale and Wheaton (1994).

[b] Other estimates range from 0.02 to 1.0 (Greene and Tishchishyna, 2000). However, Considine (2002) is one of the few studies that estimates a supply elasticity for refinery operations. Most petroleum supply elasticities also include extraction.

10G.1 Application Markets - Demand Elasticities

There are three application markets in the NDEIM: construction, agricultural, and manufacturing. Demand elasticities for the construction and manufacturing application markets were estimated using a simultaneous equation (two-stage least squares) method. This approach was also investigated for the agricultural application market; however, the estimated demand elasticity parameter for that market was not statistically significant. For this reason, a production function approach (Morgenstern, Pizer and Shih, 2002) was employed for the agricultural application market. Publicly available data developed by Dale Jorgenson and his associates (Jorgenson, 1990; Jorgenson, Gollop, and Fraumeni, 1987) were used in the regression analysis. A time series of 38 observations, from 1958 to 1995, was used to estimate the demand elasticities in both the two-stage least squares and production function approach. Both of these techniques are described below.

10G.1.1 Construction and Manufacturing Demand Elasticities

10G.1.1.1 Description of Simultaneous Equation Method

The demand elasticities for the construction and manufacturing application markets were estimated using a simultaneous equation (two-stage least squares) approach. The methodology is described below and the individual regression results are presented in Appendix 10F.

In a partial equilibrium model, supply and demand are represented by a series of simultaneous interdependent equations, in which the price and quantity produced of a product are simultaneously determined by the interaction of producers and consumers in the market. In simultaneous equations models, where one variable feeds back in to the other equations, the error terms are correlated with the endogenous variable. As a result, estimating parameter values using the ordinary least squares (OLS) regression method for each individual equation yields biased and inconsistent parameter estimates. Therefore, OLS is not an appropriate estimation technique.

Instead, a simultaneous equations approach is used. In the simultaneous equations approach both the supply and demand equations for the market are specified and parameters for the two-equation system are estimated simultaneously.

The log-log version of the model is specified as follows:

$$\text{Supply: } Q_{ts} = a_0 + a_1P_t + a_2PL_t + a_3PK_t + a_4PM_t + e_t \qquad (10G.1a)$$

$$\text{Demand: } Q_{td} = b_0 + b_1P_t + b_2HH_t + b_3I_t + v_t \qquad (10G.1b)$$

where

Q_t = log of quantity of the market product in year t

P_t = log of price of the market product in year t

PL_t = log of cost of labor inputs in year t
PK_t = log of cost of capital inputs in production in year t
PM_t = log of cost of material inputs in production in year t
HH_t = log of number of households in year t
I_t = average income per household in year t
e_t, v_t = error terms in year t

The parameter estimates $\hat{a}_1$ and $\hat{b}_1$ are the estimated price elasticity of supply and price elasticity of demand, respectively.

The first equation defines quantity supplied in each year as a function of the product price and the cost of inputs: labor, capital and materials. The second equation defines the quantity demanded in each year as a function of the production price, the number of households, and the average income per household. The equilibrium condition is that supply equals demand

$$\text{equilibrium: } Q_{ts} = Q_{td}$$

Application of this two-stage least square regression approach was successful for estimating the demand elasticity parameters for use here but was unsuccessful for estimating the supply elasticities. The supply elasticity estimates were negative and not statistically significant. Therefore, as noted above, literature estimates were used for the supply elasticities for the three application markets in the NDEIM.

To estimate the demand elasticities using this two-stage least squares approach, it is necessary to first estimate the reduced-form equation for price using OLS. The reduced-form equation expresses price as a function of all exogenous variables in the system:

$$P_t = fn(PL_t , PK_t , PM_t , HH_t , I_t)$$

The results of this regression are used to develop fitted values of the dependent price variable P_t (this is a new instrumental variable for price). The fitted values by construction will be independent of error terms in the demand equation. In the second stage regression, the fitted price variable P_t (the instrumental variable) is used as a replacement for P_t, in the demand equation. An OLS is performed on this equation, which produces a consistent, unbiased estimate of the demand elasticity b_1.

10G.1.1.2 Construction Application Market Demand Elasticity

The results of the simultaneous equation method for the construction demand elasticity are presented in Table 10G-3. The estimated demand elasticity is –0.96 and is statistically significant with a t-statistic of –3.83. This inelastic estimate implies that a 1 percent increase in price will lead to a 0.96 percent decrease in demand for construction, and means that the quantity of goods and services demanded is expected to be fairly insensitive to price changes.

Table 10G-3. Construction Demand Elasticity

Number of Observations = 29
R squared = 0.78
Adjusted R squared = 0.75

Variable	Estimated Coefficients	t-statistic
intercept	18.83	5.19
In price	–0.96	–3.83
In number of households	–1.73	–3.37
In average income per household	–1.67	5.34

10G.1.1.3 Manufacturing Application Market Demand Elasticity

The results of the simultaneous equation method for the manufacturing market are presented in Table 10G-4. The estimated demand elasticity is –0.58 and is statistically significant with a t-statistic of –2.24. This inelastic estimate implies that a 1 percent increase in price will lead to a 0.58 percent decrease in the demand for manufactured products, and means that the quantity of goods and services demanded is expected to be fairly insensitive to price changes.

Table 10G-4. Manufacturing Demand Elasticity

Number of Observations = 29
R squared = 0.83
Adjusted R squared = 0.81

Variable	Estimated Coefficients	t-statistic
intercept	6.16	0.84
In price	–0.58	–2.24
In number of households	0.19	0.23
In average income per household	0.62	1.49

10G.1.2 Agricultural Application Market Demand Elasticity

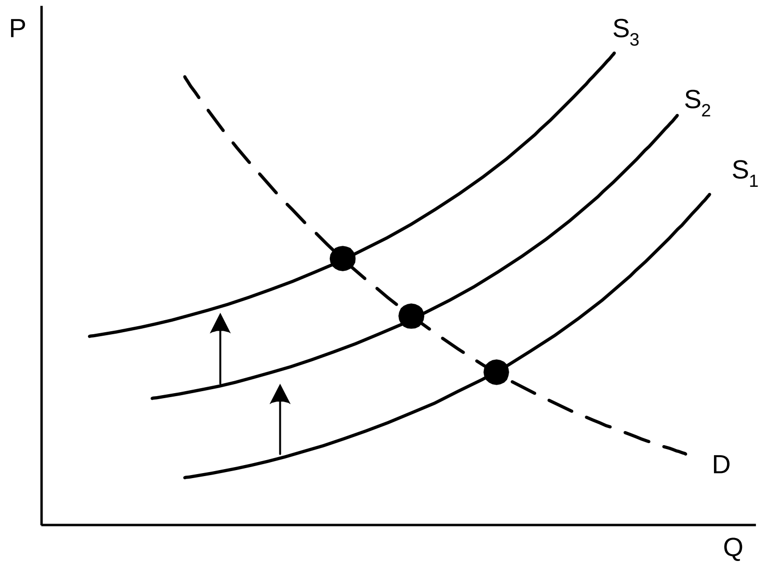
10G.1.2.1: Description of Productivity Shift Approach

When the simultaneous equation method was attempted for the agricultural application market, the resulting demand elasticity parameter estimate was not statistically significant. Thus, the demand elasticity for the agricultural market was estimated using the productivity shift approach.

This is a technique that regresses historical data for aggregate output on industry productivity (Morgenstern, Pizer, and Shih, 2002).

As shown in Figure 10G-1, changes in industry productivity represent shifts in the supply curve. The supply curve shifts in conjunction with the known output values trace-out the demand curve and enables the estimation of the demand elasticity. Because the agricultural sector is relatively small compared to the entire economy, it is reasonable to assume that the productivity changes do not shift the demand curve through income effects.

Figure 10G-1
Productivity Shifts Trace-Out Demand Curve



The demand elasticity (ξd) is estimated through a simple regression of the annual change in the natural log of outputs on change in the natural log of productivity:

$$\vartriangle \ln \text{output}_t = \xi_d \vartriangle \ln \text{prod}_t + \varepsilon_t$$

where
output$_t$ = output t is the industry output in year t,
prod$_t$ = industry productivity in year t, and
ε_t = random error term.

The change in the natural log of productivity is computed as the log difference between the annual change in input price and the annual change in output price:

$$\triangle \ln prod_t = \sum_{sh} \frac{(\upsilon_{sh,t}+\upsilon_{sh,t-1})}{\partial} (\ln P_{sh,t}-\ln P_{sh,t-1}) - (\ln PO_t-\ln PO_{t-1}) \qquad (10.G\text{-}2)$$

where

P	=	input prices,
PO	=	output prices, and
υ	=	input shares.

Eq. (10G.2) is a similar to a standard quantity-based definition of productivity (output divided by input), but expressed in terms of input and output prices. Under a competitive market with zero-profit assumptions, revenue equals cost, and the price of output must equal the price of input divided by the standard definition of productivity:

$$P_O = P_I (Q_I / Q_O)$$

Thus,

$$P_I / P_O = Q_O / Q_I$$

Where

Q_O = quantity of output
Q_I = quantity of input

Since Q_O / Q_I is a quantity based productivity, P_I / P_O is an equivalent measure of productivity according to the above equation. The difference in logged changes in P_I and P_O is a valid measure of productivity growth (Pizer, 2002).

10G.1.2.2 Agricultural Application Market Demand Elasticity

The results of the estimated agricultural model are presented in Table 10G-5. The demand elasticity estimate is −0.20 and is statistically significant with a t-statistic of 2.31. This implies that a 1 percent increase in price will lead to a 0.2 percent decrease in demand, and means that the quantity of goods and services demanded is expected to be fairly insensitive to price changes.

Table 10G-5. Agricultural Demand Elasticity

Number of Observations = 38
R squared = 0.13
Adjusted R squared = 0.11

Variable	Estimated Coefficients	t-statistic
intercept	0.02	3.49
ln productivity t	–0.20	2.31

10G.2 Application Market - Supply Elasticities

Professional literature sources were used to obtain supply elasticity estimates for the applications markets. These literature sources used are described below.

It should be noted that both of the econometric estimation methods described above, the simultaneous equation approach and the production function approach, were also attempted for the supply elasticities. However, because of the great variety of the production processes in these aggregate industry sectors (heterogeneity), parameter estimates were either not statistically significant or did not conform with standard microeconomic theory (i.e., estimates were not upward sloping).

10G.2.1 Agricultural Application Market Supply Elasticity

Obtaining reasonable estimates of supply response in agriculture has been a persistent problem since the inception of farm price support programs in the 1930s. The nonrecourse marketing loans, deficiency payments, and conservation set-asides that make up the current farm price support system distort equilibrium prices to the point that any econometric estimates are difficult to formulate or support.

A recent study by economists at the USDA’s Economic Research Service provides an approach to estimating agricultural demand elasticities (Lin et al., 2000). Taking into account recent changes in the 1996 Farm Bill, the authors measure nationwide acreage price elasticity values for the seven major agricultural crops, obtaining values ranging from 0.269 for soybeans to 0.550 for sorghum. Although a composite number for all farm output is not reported, an average value of 0.32 can be obtained by weighting the reported values by the acreage planted for each crop. This value was used for the supply elasticity in the agriculture application market. This estimated elasticity is inelastic, which means that the quantity of goods and services supplied is expected to be fairly insensitive to price changes.

Although the literature estimates vary, this estimate conforms closely to historical evidence and economic theory of small but positive supply elasticities. This determination of price having little impact on supply (referred to as inelastic supply) is consistent with a historical observation that total acreage cultivated varies little from year to year. Between 1986 and 2001, for instance, U.S. cropland harvested has ranged from 289 to 318 million acres, with an average of 305 million acres over that 15-year period. A low supply elasticity is also supported by the fact that there are few alternative uses (except in the very long run) for cropland, capital, and labor employed in farming. Abandonment or redeployment of farm assets is an often irreversible decision, and one not greatly affected by annual price swings.

10G.2.2 Construction Application Market Supply Elasticity

Although the construction market does not suffer from government-induced distortions to prices and quantities, the evidence on supply elasticity is even more varied than that for agriculture. Estimates of supply elasticity ranging from near zero to infinity have been reported in credible papers on housing construction published during the past 20 to 30 years. A literature survey paper by DiPasquale (1997) describes the methodological issues that have led to this variety of responses. A key issue is the conceptual problem of distinguishing between increases in the stock the of housing (or other structures) through new construction and changes in the flow of housing services, which can also include renovation, apartment or condominium conversion, and abandonment.

DiPasquale cites a number of published studies that suggest that a value of 1.0 for supply elasticity is appropriate. In the study that most closely matches the analysis for this regulation, Poterba (1984) estimated elasticity of new construction with respect to real house prices ranging from 0.5 to 2.3, depending on the specification. A study by Topel and Rosen investigating asset-markets and also found a short-run elasticity value of 1.0 (Topel and Rosen, 1988). Finally, DiPasquale cites one of her own papers that estimated values of 1.0 to 1.2 for the price elasticity of construction (DiPasquale and Wheaton, 1994). Based on these studies, a value of 1.0 was used for the supply elasticity in the construction application market. This unit elastic elasticity means that the quantity supplied is expected to vary directly with changes in prices.

Estimates of supply response for other portions of the construction market, namely nonresidential buildings and nonbuilding (roads and bridges, water and sewer systems, etc.), are not available in the literature. However, the similarity between technologies employed in construction of residential and other nonindustrial buildings suggests that supply elasticities should be comparable. In addition, residential construction accounts for a significant portion of construction activity. According to the Census Bureau’s most recent Annual Value of Construction Put in Place report, residential and nonindustrial buildings accounted for about 77 percent of the $842 billion in construction spending in 2001, with new residential housing making up about 33 percent (U.S. Census Bureau, 2002).

10G.2.3 Manufacturing Application Market Supply Elasticity

No supply elasticity estimates were available in the professional literature for the aggregate manufacturing sector. For this reason, a unitary supply elasticity of 1.0 was used in the model. This unit elastic elasticity means that the quantity supplied is expected to vary directly with changes in prices. A sensitivity analysis for this assumed elasticity is presented in Appendix I.

10G.3 Engine and Equipment Markets Supply Elasticity

Published sources for the price elasticity of supply for diesel engine and diesel equipment markets were not available. Therefore, the supply elasticities used in the model were estimated econometrically using a production function cost minimization approach.

10G.3.1 Production Function Cost Minimization Approach

The production function cost minimization approach for econometrically estimating the supply elasticities is based on the cost-minimizing behavior of the firm subject to production function constraints. The production function describes the relationship between output and inputs. For this analysis, a Cobb-Douglas, or multiplicative form, was used as the functional form of the production function:

$$Q_t = A\ k_t^{\alpha k}\ L_t^{\alpha L}\ M_t^{\alpha k}\ t^{\lambda} \qquad (10G\text{-}3)$$

where
Q_t = output in year t,
K_t = real capital consumed in production in year t,[N]
L_t = quantify of labor used in year t,
M_t = material inputs in year t, and
t = a time trend variable to reflect technology changes.

This equation can be written in linear form by taking the natural logarithms of each side of the equation. The parameters of this model, α_K, α_L, α_M, can then be estimated using linear regression techniques:

$$\ln Q_t = \ln A + \alpha_k \ln k_t + \alpha \ln L_t + \alpha_m \ln M_t + \lambda \ln t.$$

Under the assumptions of a competitive market and perfect competition, the elasticity of supply with respect to the price of the final product can be expressed in terms of the parameters of the production function:

$$\text{Supply Elasticity} = (\alpha_l + \alpha_m) / (1 - \alpha_l - \alpha_m) \qquad (10G\text{-}4)$$

This underlying relationship is derived from the technical production function and the behavioral profit maximization conditions. The derivation for equation (106) is provided in Appendix 10H.

[N] Capital consumed is defined as the value added minus labor expenditures, divided by the price index for capital.

In a competitive market, a firm will supply output as long as the marginal cost (MC) of producing the next unit does not exceed the marginal revenue (MR, i.e., the price). In a short-run analysis, where capital stock is assumed to be fixed (or a sunk cost of production), the firm will adjust its variable inputs of labor and material to minimize the total cost of producing a given level of output.

The supply function is estimated by minimization, subject to the technical constraints of the production function, and then setting the MC = P to determine the quantity produced as a function of market price. To maintain the desired properties of the Cobb-Douglas production function, it is necessary to place restrictions on the estimated coefficients. For example, if $\alpha_L + \alpha_M = 1$, then the supply elasticity will be undefined. Alternatively, if $\alpha_L + \alpha_M > 1$, this yields a negative supply elasticity. Thus, a common assumption is that $\alpha_K + \alpha_L + \alpha_M = 1$. This implies constant returns to scale, which is consistent with most empirical studies.

10G.3.2 Data for Estimating Engine and Equipment Supply Elasticities

The data for the supply elasticity estimation were obtained from the National Bureau of Economic Research-Center for Economic Studies (NBER-CES). All nominal values were deflated into $1987, using the appropriate price index. The following variables were used:

- value of shipments
- price index of value shipments
- production worker wages
- implicit GDP deflators
- cost of materials
- price index for materials
- real capital stock
- investment
- price index for investment
- value added
- price index for capital

The capital (k) variable used in the Cobb-Douglas regression analysis is calculated as:

$$K = (\text{Value Added} - \text{Labor Costs}) / \text{Price Index for Capital}$$

This provides a measure of capital consumed as opposed to using a measure of total capital stock in place at the firm.

10G.3.3 Engine Supply Elasticity Regression Results

The results of the estimated production function is presented in Table 10G-6. All parameter estimates are statistically significant at the 95 percent confidence level and the supply elasticity is calculated to be 3.81. This elastic elasticity estimate means that the quantities supplied in this market are expected to be very responsive to price changes.

Table 10G-6. Engine Supply Elasticity

Supply Elasticity = 3.81
Number of Observations = 33
R-squared = 0.9978
Goldfeld-Quandt F = 1.88
Note: F(14,14) = 2.46.

Variable	**Estimated Coefficients**	**t-statistic**
Intercept	0.954	24.76
ln K	0.2081	4.77
ln T	0.0215	2.37
ln M	0.5909	13.40
ln L	0.201	5.55

10G.3.4 Equipment Supply Elasticity Regression Results

The results of the estimated production functions are presented in Tables 10G-7 through 10G-12. The supply elasticities are calculated from the estimated coefficients for lnM and lnL as described in Equation G10-4. The supply elasticities range from approximately 1.0 for refrigeration to 5.4 for general industrial equipment. The average supply elasticity is 3.6. These elastic elasticity estimates means that the quantities supplied in this market are expected to be responsive to price changes.

Table 10G-7. Agricultural Supply Elasticity

Supply Elasticity = 2.14
Number of Observations = 33
R-squared = 0.9969
Goldfeld-Quandt F = 2.01
Note: F(14,14) = 2.46.

Variable	**Estimated Coefficients**	**t-statistic**
Intercept	1.1289	20.81
ln K	0.3189	11.12
ln T	–0.0241	–3.10
ln M	0.4952	10.29
ln L	0.1858	4.64

Table 10G-8. Construction Supply Elasticity

Supply Elasticity = 3.31
Number of Observations = 33
R-squared = 0.9926
Goldfeld-Quandt F = 1.76
Note: F(14,14) = 2.46.

Variable	**Estimated Coefficients**	**t-statistic**
Intercept	1.172	28.54
ln K	0.2318	5.83
ln T	–0.0617	–7.08
ln M	0.1511	4.54
ln L	0.6172	13.97

Table 10G-9. Industrial Supply Elasticity

Supply Elasticity = 5.37
Number of Observations = 33
R-squared = 0.9949
Goldfeld-Quandt F = 1.23
Note: F(14,14) = 2.46

Variable	**Estimated Coefficients**	**t-statistic**
Intercept	0.6927	18.29
ln K	0.157	3.47
ln T	–0.00739	–0.76
ln M	0.0412	0.96
ln L	0.8018	21.90

Table 10G-10. Garden

Supply Elasticity = 3.37
Number of Observations = 33
R-squared = 0.9963
Goldfeld-Quandt F = 1.18
Note: F(14,14) = 2.46

Variable	**Estimated Coefficients**	**t-statistic**
Intercept	0.6574	13.34
ln K	0.2287	3.75
ln T	0.0413	2.78
ln M	0.0644	1.72
ln L	0.7069	11.23

Table 10G-11. Gensets

Supply Elasticity = 2.91
Number of Observations = 33
R-squared = 0.9909
Goldfeld-Quandt F = 1.16
Note: F(14,14) = 2.46.

Variable	**Estimated Coefficients**	**t-statistic**
Intercept	1.1304	11.09
ln K	0.2557	3.60
ln T	0.0325	2.73
ln M	0.3797	4.67
ln L	0.3646	4.51

Table 10G-12. Pumps

Supply Elasticity = 2.83
Number of Observations = 33
R-squared = 0.9979
Goldfeld-Quandt F = 1.40
Note: F(14,14) = 2.46

Variable	Estimated Coefficients	t-statistic
Intercept	0.9367	19.01
ln K	0.2608	4.45
ln T	–0.207	–1.74
ln M	0.0891	1.57
ln L	0.6501	14.48

10G.4 Diesel Fuel Supply Elasticity: Literature Estimate

Very few studies have attempted to quantify supply responsiveness for individual refined products, such as diesel fuel. For example, a study for the California Energy Commission stated “There do not seem to be credible estimates of gasoline supply elasticity” (Finizza, 2002). However, sources agree that refineries have little or no ability to change output in response to price: high fixed costs compel them to operate as close to their capacity limit as possible. The Federal Trade Commission (FTC) analysis made this point explicitly (FTC, 2001).

Greene and Tishchishyna (2000) reviewed supply elasticity estimates available in the literature. The supply elasticity values cited in most of these studies were for “petroleum” or “oil” production in the United States, which includes exploration, distribution and refining activities. The lowest short-term numbers cited were 0.02 to 0.05, with long-run values ranging from 0.4 to 1.0. It seems likely that these extremely low numbers are influenced by the limited domestic supply of crude petroleum and the difficulty of extraction.

A recent paper by Considine (2002) provides one of the few supply elasticity estimates for refining production (excluding extraction and distribution) based on historical price and quantity data. In this study, Considine estimates a refining production supply elasticity of 0.24. This estimate is for aggregate refinery production and includes distillate and nondistillate fuels. Because petroleum products are made in strict proportion and refineries have limited ability to adjust output mix in the short to medium run, it is reasonable to assume that supply is relatively inelastic and similar across refinery products. This value of 0.24 was used for the supply elasticity for this market. This estimated elasticity is inelastic, which means that the quantity of goods and services supplied is expected to be fairly insensitive to price changes.

APPENDIX 10H: Derivation of Supply Elasticity

This appendix derives the underlying relationship for the supply elasticity used in the production function approach described in Appendix 10G.

Cobb-Douglas:

$Q = L^{\alpha} k^{1-\alpha}$ where Q = output
L = labor input
k = capital input

Cost Minimization:

Marginal Revenue Product of Labor = Wage Rate

$MRP_L = P \bullet MP_L = w$

$$MP_L = \frac{\partial Q}{\partial L} = \alpha L^{\alpha-1} k^{1-\alpha}$$

$$P \bullet MP_L = P\alpha\, L^{\alpha-1} k^{1-\alpha} = w$$

$$L^{\alpha-1} = \frac{w}{P\alpha k^{1-\alpha}}$$

$$L^{1-\alpha} = \frac{P\alpha k^{1-\alpha}}{w}$$

$$L = \left(\frac{P\alpha k^{1-\alpha}}{w}\right)^{\frac{1}{1-\alpha}} = \left(\frac{P\alpha}{w}\right)^{\frac{1}{1-\alpha}} k$$

Substitute Back into Cobb-Douglas:

$$y = \left[\left(\frac{P\alpha}{w}\right)^{\frac{1}{1-\alpha}} k\right]^{\alpha} k^{1-\alpha}$$

$$y = \left(\frac{P\alpha}{w}\right)^{\frac{\alpha}{1-\alpha}} k = p^{\frac{\alpha}{1-\alpha}} \left(\frac{\alpha}{w}\right)^{\frac{\alpha}{1-\alpha}} k$$

$$\ln y = \frac{\alpha}{1-\alpha} \ln P + \frac{\alpha}{1-\alpha} \ln\left(\frac{\alpha}{w}\right) + \ln k$$

$$\boxed{\frac{\partial \ln y}{\partial \ln P} = \frac{\alpha}{1-\alpha} = \text{Supply Elasticity}}$$

APPENDIX 10I: Sensitivity Analysis

The Economic Impact Analysis presented in this Chapter 10 is based on the Nonroad Diesel Economic Impact Model (NDEIM) developed for this analysis. The NDEIM reflects certain assumptions about behavioral responses (modeled by supply and demand elasticities) and how costs are treated by producers. This Appendix presents a sensitivity analysis for several model components by varying how they are treated. Five model components are examined:

- Scenario 1: alternative market supply and demand elasticity parameters
- Scenario 2: alternative ways to treat fuel market costs
- Scenario 3: alternative way to treat operating costs
- Scenario 4: alternatives way to treat engine and equipment fixed costs
- Scenario 5: alternative discount rates

The results of these sensitivity analyses are presented below. All of the results are presented for 2013 only. Also, the application market results are presented without adjusting by the operating savings. Instead, these are added into the welfare changes separately.

In general, varying the model parameters does not significantly change the results of the economic impact assessment analysis presented above. Total social costs are about the same across all sensitivity analysis scenarios, $1,202.4 million, with the exception of Scenario 2 (alternative ways to treat fuel market costs). The base case models fuel market costs based on average variable + fixed costs. Two alternatives were considered: maximum total costs and maximum variable costs. In both of these alternatives, the social costs of the rule (less operating savings and fuel marker and spillover costs) would increase by about 2 percent, to about $1,229 million.

In addition, varying these model parameters does not significantly affect the way the social costs are borne. In all cases, the application markets bear the majority of the burden (about 82 percent), although there are small differences in the way the costs are borne among the markets. There are also differences in the way the application market costs are shared among producers and consumers in that market, especially for Scenario 1. The exception is Scenario 2, the fuel cost scenario. In the maximum total cost scenario, the share of the social costs borne by the application market exceeds the social costs of the rule ($1,412.1 million versus $1,229.3 million for the rule), indicating that the refiners would gain from the proposal (about $146.3 million). In the maximum variable cost scenario, the share borne by the refiners would increase from $7.8 million to $200.9 million, and the share borne by the application market would decrease from $1,231.8 million to $1,066 million.

With regard to the market analysis, expected price and quantity changes are about the same as in the base case. The expected change in engine prices is the same except in Scenario 4 (includes engine and equipment fixed costs), in which the expected engine price increase goes up about 6 percent (from 22.88 percent to 24.22 percent). The expected change in equipment prices is also similar across scenarios with the exception of Scenario 4, in which the expected equipment price increase goes up about 11 percent (from 5.23 percent to 5.83 percent). For the application market, the expected price increase remains between 0.01 percent and 0.02 percent. Expected fuel price changes are somewhat more volatile across the scenarios, ranging from a 1.77 percent increase to a 4.54 increase, compared to 3.09 percent increase in the base case. Finally, expected decreases in the quantities produced do not change much. The largest expected quantity decrease is 0.019 for the equipment market in Scenario1; the smallest is 0.006 for the application markets in Scenario 1.

10I.1 Model Elasticity Parameters

Key model parameters include supply and demand elasticity estimates used by the model to characterize behavioral responses of producers and consumers in each market.

Consumer demand and producer supply responsiveness to changes in the commodity prices are referred to by economists as “elasticity.” The measure is typically expressed as the percentage change in quantity (demanded or supplied) brought about by a percent change in own price. A detailed discussion regarding the estimation and selection of the elasticities used in the NDEIM are discussed in Appendix 10G. This component of the sensitivity analysis examines the impact of changes in selected elasticity values, holding other parameters constant. The goal is to determine whether alternative elasticity values significantly alter conclusions in this report.

10I.1.1 Application Markets (Supply and Demand Elasticity Parameters)

The choice of supply and demand elasticities for the *application market* is important because changes in quantities in the application markets are the key drivers in the derived demand functions used to link impacts in the engine, equipment, and fuel markets. In addition, the distribution of regulatory costs depends on the *relative supply and demand elasticities* used in the analysis. For example, consumers will bear less of the regulatory burden if they are more responsive to price changes than producers.

Table 10I-1 reports the upper- and lower-bound values of the application market elasticity parameters (supply and demand) used in the sensitivity analysis. The variation in estimates reported in the literature were used for supply elasticity ranges. For the manufacturing market, an assumed elasticity of 1.0 was used. For the purpose of this sensitivity analysis, the same upper and lower bounds were used as for the construction market. For demand elasticity values, a 90 percent confidence interval was computed using the coefficient and standard error values reported in the econometric analysis (see Appendix 10G).

Table 10I-1. Sensitivity Analysis of the Supply and Demand Elasticities for the Application Markets

Parameter/Market	Elasticity Source	Upper Bound	Base Case	Lower Bound
Supply elasticity				
Construction	Literature estimate	2.3	1.00	0.50
Agriculture	Literature estimate	0.55	0.32	0.027
Manufacturing	Assumed value	2.3	1.00	0.50
Demand elasticity				
Construction	EPA estimate	–1.39	–0.96	–0.534
Agriculture	EPA estimate	–0.35	–0.20	–0.054
Manufacturing	EPA estimate	–1.02	–0.58	–0.140

Note: For literature estimates, the variations in estimates reported were used to develop elasticity ranges. In contrast, EPA computed upper- and lower-bound estimates using the coefficient and standard error values associated with its econometric analysis and reflect a 90 percent confidence interval.

The results of the NDEIM using these alternative elasticity values are reported in Tables 10I-2 and 10I-3. As can be seen in those tables, market price and quantity increases vary negligibly across the upper- and lower-bound sensitivity scenarios.

The change in total social surplus for 2013 also remains essentially unchanged across all scenarios and is approximately the same as for the proposed program ($1,202.5 million). However, consumers in the application market bear a *smaller* share of the social costs when they are more responsive to price changes relative to producers (supply lower bound and demand upper bound scenarios). As shown, consumers bear approximately 33 and 46 percent, respectively, in these scenarios compared to 58 percent in the base case. In contrast, they bear a *higher* share (up to 78 percent) when they are less responsive to price changes relative to producers (supply upper bound and demand lower bound scenarios). While the burden of the fuel market changes slightly, it always remain below 1 percent of the social costs.

Table 10I-2. Application Market Sensitivity Analysis for Supply Elasticities[a,b]

	Base Case		Supply Upper Bound		Supply Lower Bound	
Scenario	**Absolute**	**Relative**	**Absolute**	**Relative**	**Absolute**	**Relative**
Application Markets						
Price ($/q)	NA	0.02%	NA	0.02%	NA	0.01%
Quantity (q/yr)	NA	–0.010%	NA	–0.014%	NA	–0.007%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$914.1	NA	$412.1	NA
Change in Producer Surplus ($$10^6$/yr)	$515.6	NA	$313.2	NA	$825.0	NA
Change in Total Surplus ($$10^6$/yr)	$1,231.7	NA	$1,227.3	NA	$1,237.1	NA
Equipment Markets						
Price ($/q)	$1,016.49	5.23%	$1,041.63	5.23	$1,018.68	5.23%
Quantity (units/yr)	–118	–0.014%	–161	–0.019%	–63	–0.008%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$117.6	NA	$114.3	NA
Engine Markets						
Price ($/q)	$839.71	22.88%	$839.65	22.88%	$839.78	22.88%
Quantity (units/yr)	–69	–0.013%	–95	–0.017%	–40	–0.007%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$30.2	NA	$30.2	NA
Fuel Markets						
Price ($/q)	$0.03	3.09%	$0.03	3.07%	$0.03	3.12%
Quantity (gal/yr)	–293,593	–0.014%	–401,456	–0.020%	–163,005	–0.008%
Change in Producer Surplus ($$10^6$/yr)	$7.8	NA	$10.6	NA	$4.3	NA
Change in Market Surplus ($$10^6$/yr)	$1,385.7	NA	$1,385.7	NA	$1,385.8	NA
NR Spillover	$51.2	NA	$51.2	NA	$5.12	NA
Operating and Marker Cost ($$10^6$/yr)	–$234.6	NA	–$234.6	NA	–$234.6	NA
Social Costs ($$10^6$/yr)	$1,202.4	NA	$1,202.3	NA	$1,202.4	NA

[a] Sensitivity analysis is presented for 2013.

[b] Figures are in 2001 dollars.

Table 10I-3. Application Market Sensitivity Analysis for Demand Elasticities[a,b]

Scenario	Base Case		Demand Upper Bound		Demand Lower Bound	
	Absolute	Relative	Absolute	Relative	Absolute	Relative
Application Markets						
Price ($/q)	NA	0.02%	NA	0.01%	NA	0.02%
Quantity (q/yr)	NA	–0.010%	NA	–0.013%	NA	–0.006%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$566.7	NA	$970.9	NA
Change in Producer Surplus ($$10^6$/yr)	$515.6	NA	$662.4	NA	$265.3	NA
Change in Total Surplus ($$10^6$/yr)	$1,231.7	NA	$1,229.0	NA	$1,236.1	NA
Equipment Markets						
Price ($/q)	$1,016.49	5.23%	$1,015.45	5.23%	$1,018.19	5.23%
Quantity (units/yr)	–118	–0.014%	–145	–0.018%	–72	–0.009%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$116.9	NA	$114.7	NA
Engine Markets						
Price ($/q)	$839.71	22.88%	$839.67	22.88%	$839.78	22.88%
Quantity (units/yr)	–69	–0.013%	–86	–0.016%	–42	–0.008%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$30.2	NA	$30.2	NA
Fuel Markets						
Price ($/q)	$0.03	3.09%	$0.03	3.08%	$0.03	3.11%
Quantity (gal/yr)	–293,593	–0.014%	–359,059	–0.018%	–184,642	–0.009%
Change in Producer Surplus ($$10^6$/yr)	$7.8	NA	$9.5	NA	$4.8	NA
Change in Market Surplus ($$10^6$/yr)	$1,385.7	NA	$1,385.7	NA	$1,385.8	NA
NR Spillover	$51.2	NA	$51.2	NA	$51.2	NA
Operating and Marker Cost ($$10^6$/yr)	–$234.6	NA	–$234.6	NA	–$234.6	NA
Social Costs ($$10^6$/yr)	$1,202.4	NA	$1,202.3	NA	$1,202.4	NA

[a] Sensitivity analysis is presented for 2013.
[b] Figures are in 2001 dollars.

10I.1.2 Equipment, Engine and Diesel Fuel Markets (Supply Elasticity Parameters)

Sensitivity analysis was also conducted for the engine, equipment, and diesel fuel market supply elasticities. The range of elasticity values evaluated for each market are provided in Table 10I-4. The engine and equipment market supply elasticities are derived econometrically.

Therefore, the upper and lower bound values were computed using the coefficient and standard error values associated with the econometric analysis and reflect a 90 percent confidence interval (see Appendix 10G).

The fuel market supply elasticity was obtained from the literature. The value for the lower bound for the sensitivity analysis is based on the range of available estimates. The value for the upper bound was derived from a set of regulatory studies of the petroleum refining industry that were conducted using a techno-economic method to estimate supply costs at the individual refinery level (EPA, 2000; CRA/BOB, 2000; MathPro, 2002). Synthetic industry supply curves (i.e., marginal cost curves) were developed from these studies and yielded supply elasticities ranging from 0.2 to 2.0. Therefore, the sensitivity analysis uses 2.0 as an upper bound for the supply elasticity of nonroad diesel fuel.

Three sets of sensitivity results are presented in Tables 10I-5, 10I-6, and 10I-7, where supply elasticities are changed in the equipment, engines, and fuel markets, respectively.

Table 10I-4
Engine, Equipment, and Diesel Fuel Market Sensitivity Analysis for Supply Elasticity Parameters

Market	Elasticity Source	Upper Bound	Base Case	Lower Bound
Supply				
Engines	EPA Estimate	7.64	3.81	2.33
Equipment				
Construction	EPA Estimate	6.06	3.31	2.09
Agriculture	EPA Estimate	3.72	2.14	1.31
Refrigeration	EPA Estimate	5.62	2.83	1.62
Industrial	EPA Estimate	12.93	5.37	2.90
Garden	EPA Estimate	7.96	3.37	1.82
Generator	EPA Estimate	12.14	2.91	1.12
Pumps	EPA Estimate	5.62	2.83	1.62
Diesel fuel	Literature Estimate	2.00	0.20	0.04

Note: For literature estimates, the variations in estimates reported were used to develop elasticity ranges. In contrast, EPA computed upper- and lower-bound estimates using the coefficient and standard error values associated with its econometric analysis and reflect a 90 percent confidence interval.

For the engine and equipment markets (Tables 10I-5 and 10I-6), all quantitative estimates for both market impacts (price and quantity changes) and social impacts (how the burden is shared across markets) remain essentially unchanged when compared to the proposed program, across both the upper and lower bound supply elasticity scenarios for equipment and engines. These results imply that the results presented in Section 10.1 are not sensitive to the supply elasticity values used in the engine and equipment markets. This is because the derived demand for engines and equipment is highly inelastic (it is a function of the inelastic demand and supply in the application markets), and so almost all of the compliance costs are passed on to the application markets through price increases.

For the fuel market (Table 10I-7), there is some variation in impacts. As the fuel market supply elasticity becomes more elastic (supply upper bound; producers become more sensitive to price changes), the change in fuel prices increases from 3.09 percent in the base case to 3.14 percent in the supply upper bound case, and producer welfare losses fall from $7.8 million to about $1.0 million. In contrast, as the fuel market supply elasticity becomes less elastic (supply lower bound; producers become less responsive to price changes), the change in fuel prices decreases from 3.09 percent in the base case to 2.78 percent in the lower bound case, and producer welfare losses increase from $7.8 million to $47.7 million.

It should be remembered that the demand elasticities for the equipment and engine diesel fuel markets are derived as part of the model, and therefore sensitivity analysis was not conducted on those parameters.[O] In other words, the change in the application market quantities determines the demand responsiveness in the engine, equipment, and diesel fuel markets. As a result, the demand sensitivity analysis for these markets is indirectly shown in Table 10I-2. Nonroad diesel equipment and fuel expenditures are relatively small shares of total production costs for the application markets. Therefore changes in these input prices do not significantly alter input demand (i.e., demand in these markets is highly inelastic).

[O] For a discussion of the concept of derived demand, see Section 10.2.2.3 Incorporating Multimarket Interactions.

Table 10I-5. Equipment Market Supply Elasticity Sensitivity Analysis[a,b]

Scenario	Base Case		Supply Upper Bound		Supply Lower Bound	
	Absolute	Relative	Absolute	Relative	Absolute	Relative
Application Markets						
Price ($/q)	NA	0.02%	NA	0.02%	NA	0.02%
Quantity (q/yr)	NA	–0.010%	NA	–0.010%	NA	–0.010%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$717.1	NA	$714.7	NA
Change in Producer Surplus ($$10^6$/yr)	$515.6	NA	$516.5	NA	$514.5	NA
Change in Total Surplus ($$10^6$/yr)	$1,231.7	NA	$1,233.5	NA	$1,229.2	NA
Equipment Markets						
Price ($/q)	$1,016.49	5.23%	$1,018.73	5.23%	$1,013.48	5.22%
Quantity (units/yr)	–118	–0.014%	–118	–0.014%	–118	–0.014%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$114.2	NA	$118.6	NA
Engine Markets						
Price ($/q)	$839.71	22.88%	$839.72	22.88%	$839.71	22.88%
Quantity (units/yr)	–69	–0.013%	–67	–0.012%	–70	–0.013%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$30.2	NA	$30.2	NA
Fuel Markets						
Price ($/q)	$0.03	3.09%	$0.03	3.09%	$0.03	3.09%
Quantity (gal/yr)	–293,593	–0.014%	–294,171	–0.014%	–292,828	–0.014%
Change in Producer Surplus($$10^6$/yr)	$7.8	NA	$7.8	NA	$7.7	NA
Change in Market Surplus ($$10^6$/yr)	$1,385.7	NA	$1,385.7	NA	$1,385.7	NA
NR Spillover	$51.2	NA	$51.2	NA	$51.2	NA
Operating and Marker Cost ($$10^6$/yr)	–$234.6	NA	–$234.6	NA	–$234.6	NA
Social Costs ($$10^6$/yr)	$1,202.4	NA	$1,202.4	NA	$1,202.4	NA

[a] Sensitivity analysis is presented for 2013.

[b] Figures are in 2001 dollars.

Table 10I-6. Engine Market Supply Elasticity Sensitivity Analysis[a,b]

	Base Case		Supply Upper Bound		Supply Lower Bound	
Scenario	**Absolute**	**Relative**	**Absolute**	**Relative**	**Absolute**	**Relative**
Application Markets						
Price ($/q)	NA	0.02%	NA	0.02%	NA	0.02%
Quantity (q/yr)	NA	–0.010%	NA	–0.010%	NA	–0.010%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$716.1	NA	$716.0	NA
Change in Producer Surplus ($$10^6$/yr)	$515.6	NA	$515.6	NA	$515.6	NA
Change in Total Surplus ($$10^6$/yr)	$1,231.7	NA	$1,231.7	NA	$1,231.6	NA
Equipment Markets						
Price ($/q)	$1,016.49	5.23%	$1,016.55	5.23%	$1,016.43	5.23%
Quantity (units/yr)	–118	–0.014%	–118	–0.014%	–118	–0.014%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$116.1	NA	$116.1	NA
Engine Markets						
Price ($/q)	$839.71	22.88%	$839.80	22.88%	$839.61	22.88%
Quantity (units/yr)	–69	–0.013%	–70	–0.013%	–69	–0.013%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$30.2	NA	$30.3	NA
Fuel Markets						
Price ($/q)	$0.03	3.09%	$0.03	3.09%	$0.03	3.09%
Quantity (gal/yr)	–293,593	–0.014%	–293,603	–0.014%	–293,580	–0.014%
Change in Producer Surplus ($$10^6$/yr)	$7.8	NA	$7.8	NA	$7.8	NA
Change in Market Surplus ($$10^6$/yr)	$1,385.7	NA	$1,385.7	NA	$1,385.7	NA
NR Spillover	$51.2	NA	$51.2		$51.2	
Operating and Marker Cost ($$10^6$/yr)	–$234.6	NA	–$234.6	NA	–$234.6	NA
Social Costs ($$10^6$/yr)	$1,202.4	NA	$1,202.4	NA	$1,202.4	NA

[a] Sensitivity analysis is presented for 2013.

[b] Figures are in 2001 dollars.

Table 10I-7. Fuel Market Supply Elasticity Sensitivity Analysis[a,b]

	Base Case		Supply Upper Bound		Supply Lower Bound	
Scenario	**Absolute**	**Relative**	**Absolute**	**Relative**	**Absolute**	**Relative**
Application Markets						
Price ($/q)	NA	0.02%	NA	0.02%	NA	0.02%
Quantity (q/yr)	NA	–0.010%	NA	–0.010%	NA	–0.010%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$720.0	NA	$692.8	NA
Change in Producer Surplus ($$10^6$/yr)	$515.6	NA	$518.5	NA	$499.2	NA
Change in Total Surplus ($$10^6$/yr)	$1,231.7	NA	$1,238.5	NA	$1,191.9	NA
Equipment Markets						
Price ($/q)	$1,016.49	5.23%	$1,016.46	5.23%	$1,016.66	5.23%
Quantity (units/yr)	–118	–0.014%	–119	–0.014%	–114	–0.014%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$116.1	NA	$115.9	NA
Engine Markets						
Price ($/q)	$839.71	22.88%	$839.71	22.88%	$839.72	22.88%
Quantity (units/yr)	–69	–0.013%	–70	–0.013%	–67	–0.012%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$30.2	NA	$30.2	NA
Fuel Markets						
Price ($/q)	$0.03	3.09%	$0.03	3.14%	$0.03	2.78%
Quantity (gal/yr)	–293,593	–0.014%	–295,287	–0.014%	–283,979	–0.014%
Change in Producer Surplus ($$10^6$/yr)	$7.8	NA	$0.9	NA	$47.7	NA
Change in Market Surplus ($$10^6$/yr)	$1,385.7	NA	$1,385.7	NA	$1,385.8	NA
NR Spillover	$51.2	NA	$51.2	NA	$51.2	NA
Operating and Marker Cost ($$10^6$/yr)	–$234.6	NA	–$234.6	NA	–$234.6	NA
Social Costs ($$10^6$/yr)	$1,202.4	NA	$1,202.4	NA	$1,202.4	NA

[a] Sensitivity analysis is presented for 2013.

[b] Figures are in 2001 dollars.

10.I.2 Fuel Market Supply Shift Alternatives

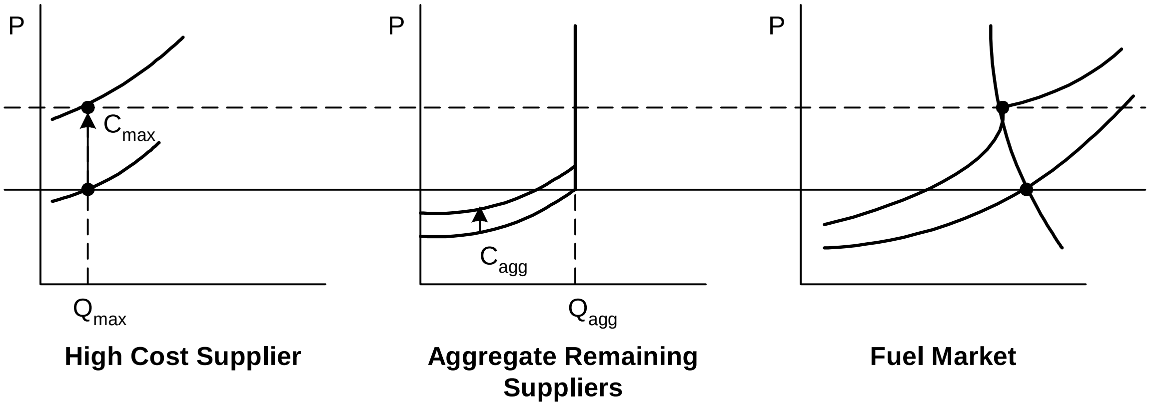
Section 10.2 discusses alternative approaches to shifting the supply curve in the market model. Three alternatives for the fuel market supply shift are investigated in this sensitivity analysis:

- Total average (variable + fixed) cost shift—the results presented in Section 10.1 and the appendices are generated using this cost shift.
- Total maximum (variable + fixed) cost shift
- Variable maximum cost shift

To model the total and variable maximum cost scenarios, the high-cost producer is represented by a separate supply curve as shown in Figure 10I-1. The remainder of the market is represented as a single aggregate supplier. The high-cost producer's supply curve is then shifted by C_{max} (either total or variable), and the aggregate supply curve is shifted by C_{agg}. Using this structure, the high-cost producer will determine price as long as

- the decrease in market quantity does not shut down the high-cost producer, and
- the supply from aggregate producers is highly inelastic (i.e., remaining producers are operating close to capacity); thus, the aggregate producers cannot expand output in response to the price increase.

Figure 10I-1
High Cost Producer Drives Price Increases



Note that the aggregate supply curve is no longer shifted by the average compliance costs but slightly less than the average because the high-cost producer has been removed. The adjusted average aggregate cost shift (C_{agg}) is calculated from the following:

$$C_{ave}*Q_{tot} = C_{max} * Q_{max} + C_{agg} * Q_{agg} \qquad (10I.2)$$

where C_{ave} is the average control cost for the total population; Q_{max}, C_{max}, and Q_{agg}, C_{agg} are the baseline output and cost shift for the maximum cost producer; and the baseline output and cost shift for the remaining aggregate producers, respectively.

The results of this sensitivity analysis are reported in Table 10I-8.

Table 10I-8
Sensitivity Analysis to Cost Shifts in the Diesel Fuel Market

	Average Total Scenario		**Maximum Total Scenario**		**Maximum Variable Scenario**	
Scenario	**Absolute Change**	**Relative Change (%)**	**Absolute Change**	**Relative Change (%)**	**Absolute Change**	**Relative Change (%)**
Application Markets						
Price ($/q)	NA	0.02%	NA	0.02%	NA	0.01%
Quantity (q/yr)	NA	–0.010%	NA	–0.012%	NA	–0.009%
Change in Consumer Surplus ($\$10^6$/yr)	$716.1	NA	$814.7	NA	$612.3	NA
Change in Producer Surplus ($\$10^6$/yr)	$515.6	NA	$597.4	NA	$453.7	NA
Change in Total Surplus ($\$10^6$/yr)	$1,231.7	NA	$1,412.1	NA	$1,066.0	NA
Equipment Markets						
Price ($/q)	$1,016.49	5.23%	$1,015.75	5.23%	$1,017.06	5.23%
Quantity (units/yr)	–118	–0.014%	–136	–0.016%	–104	–0.013%
Change in Producer Surplus ($\$10^6$/yr)	$116.1	NA	$116.7	NA	$115.6	NA
Engine Markets						
Price ($/q)	$839.71	22.88%	$839.69	22.88%	$839.73	22.88%
Quantity (units/yr)	–69	–0.013%	–80	–0.015%	–61	–0.011%
Change in Producer Surplus ($\$10^6$/yr)	$30.2	NA	$30.2	NA	$30.2	NA
Fuel Markets						
Price ($/q)	$0.03	3.09%	$0.04	4.54%	$0.02	1.77%
Quantity (gal/yr)	–293,593	–0.014%	–337,228	–0.017%	–259,056	–0.013%
Change in Producer Surplus ($\$10^6$/yr)	$7.8	NA	$–146.3	NA	$200.9	NA
Change in Market Surplus ($\$10^6$/yr)	$1,385.7	NA	$1,412.7	NA	$1,412.8	NA
NR Spillover	$51.2	NA	$51.2	NA	$51.2	NA
Operating and Marker Cost ($\$10^6$/yr)	–$234.6	NA	–$234.6	NA	–$234.6	NA
Social Costs ($\$10^6$/yr)	$1,202.4	NA	$1,229.3	NA	$1,229.4	NA

[a] Sensitivity analysis is presented for 2013.
[b] Figures are in 2001 dollars.

The total and variable maximum cost shift scenarios lead to different conclusions for two important variables: the estimated market price increase for diesel fuel and the estimated welfare impact for affected refineries. Under the base case (total average cost scenario), refiners pass most of the average compliance costs on to the application markets, and the net decrease in producer surplus for refiners is relatively small (about $7.8 million, or 0.6 percent of total social costs), and prices are expected to increase about 3.09 percent. Note that these are industry averages, and individual refiners will gain or lose because compliance costs vary across individual refineries.

In the total maximum cost scenario, the highest operating cost refinery determines the new market price through the impacts on both fixed and variable costs. This refinery has the highest per-unit supply shift, which leads to a higher price increase relative to the average cost scenario. As a result, all refiners except the highest cost refiner would be expected to benefit from the rule, by about $146.3 million. This is because the change in market price would exceed the additional per-unit compliance costs for most of the refineries (i.e., most refiners have costs less than the costs for the highest operating cost refinery). Consequently, in this scenario the producers and consumers in the application market are expected to bear a larger share of the total cost of the program ($1,412.1 million, compared to $1,231.7 million for the welfare costs of the proposed program less the operating savings).

The variable maximum cost scenario is similar to the total maximum cost scenario because the highest cost refinery determines the with-regulation market price. However, the variable maximum cost scenario leads to an expected price increase that is smaller than the total maximum cost scenario because the refiner supply shift includes only variable compliance costs. In other words, the refiners do not pass along any fixed costs; they absorb the fixed costs. Thus, in this scenario, the expected refinery welfare loss is greater than for the propose program, increasing from $7.8 million to $200.9 million. Similarly, the expected welfare loss to the application markets (without considering the operating savings) decreases from $1,412.1 million to $1,066 million

The results of this sensitivity analysis suggest that the expected impacts on producers and consumers in the application markets and on refiners is affected by how refinery costs are modeled. The NDEIM models these costs based on the average (variable + fixed) cost scenario, reflecting a competitive market situation in all regional markets. However, if the highest cost refinery drives the new market price, then prices are expected to increase more, although output does not contract. In this case, consumers and producers in the application market would be expected to bear more than the cost of the rule. However, if only the highest cost refinery's variable costs drive the new market price, then prices are expected to increase less, and producers and consumer will bear less of the burden, with refiners bearing more.

10I.3 Operating Cost Scenario

Changes in operating costs resulting from lower sulfur content nonroad diesel fuel are included in the social cost estimates presented in Section 10.1. However, because of the uncertainty of how these savings will effect individual equipment purchase decisions, operating savings were not included in the market and analysis and were added to social costs after changes in price and quantity were estimated. The results of this analysis are included in Table 10I.9.

In this sensitivity analysis, operating saving are modeled as a cost reduction (benefit) for producers in the application markets. To allow comparison of the results to the base case, the base case is adjusted by adding all the operating savings to the producer surplus, making it \$273.7 million. This is because application market producers are the users of diesel equipment and therefore it makes intuitive sense that these benefits accrue to them. In this scenario, operating cost savings are treated as negative supply shift for the application supply curves. When the operating costs are included in the total welfare costs, the social costs for this scenario are about the same as the base case (about \$1,202 million). The burden across the markets is also unchanged. The price increase and quantity decrease in the application markets is expected to be smaller. This is because by including operating savings in the supply shift, the magnitude of the shift decreases. This leads to a smaller price and quantity change in the application market.

At the same time, the distribution of costs between producers and consumers in the application market changes when operating costs are treated differently in the model. In the NDEIM, application consumers bear 72 percent of the burden of the loss of welfare surplus in the application market, while producers bear the other 28 percent. This is because this scenario assumes that application market consumers do not make market decisions based on operating costs, and that they expect to run their equipment as before. Producers are not expected to pass along operating savings to their customers. When the operating savings are included in the model, the way the cost burden is shared changes 58 percent for the application market consumers and 42 percent for the application market producers. Prices increase less and output decreases less. In other words, the impacts of the operating savings are shared among the producers and consumers.

Table 10I-9
Operating Savings Included in the Market Analysis[a]

Scenario	Base Case (2013)		Adding Operating Savings To App	
	Absolute Change	Relative Change (%)	Absolute Change	Relative Change (%)
Application Markets				
Price ($/q)	NA	0.02%	NA	0.01%
Quantity (q/yr)	NA	–0.010%	NA	–0.008%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$577.6	NA
Change in Producer Surplus ($$10^6$/yr)	$273.7	NA	$414.7	NA
Change in Total Surplus ($$10^6$/yr)	$989.8	NA	$992.2	NA
Equipment Markets				
Price ($/q)	$1,016.49	5.23%	$1,017.50	5.23%
Quantity (units/yr)	–118	–0.014%	–95	–0.011%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$115.3	NA
Engine Markets				
Price ($/q)	$839.71	22.88%	$839.75	22.88%
Quantity (units/yr)	–69	–0.013%	–56	–0.010%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$30.2	NA
Fuel Markets				
Price ($/q)	$0.03	3.09%	$0.03	3.10%
Quantity (gal/yr)	–293,593	–0.014%	–235,921	–0.012%
Change in Producer Surplus ($$10^6$/yr)	$7.8	NA	$6.2	NA
NR Spillover	$51.2	NA	$51.2	NA
Marker Cost	$7.3	NA	$7.3	NA
Total Social Cost	$1,202.4	NA	$1,202.5	NA

[a] Sensitivity analysis is presented for 2013.

10I.4 Engine and Equipment Fixed Cost Shift Scenario

As discussed in Section 10.3 only the variable costs are used to shift the supply curve in the engines and equipment markets. Fixed costs are assumed to be R&D costs that are absorbed by engine and equipment markets over a 5-year period and hence do not affect market prices or quantities. As a result, producers are not able to pass any of these costs on and bear all fixed costs as a decrease in producer surplus.

In this scenario, the supply shift for engine producers includes the fixed and variable compliance costs. The results are presented in Table 10I-10. In this scenario, engine producers are able to pass along the majority of the fixed compliance costs to the downstream markets rather than absorb them as a one-to-one reduction in profits. As expected, this scenario leads to a higher projected price increases for the engine and equipment markets (from 5.2 percent in the baseline case to 5.8 percent for equipment markets and from 22.9 percent in the baseline case to 24.2 percent for engine markets). These costs are passed on to the application markets, and their expected share of the compliance burden increases from 90 percent to 99 percent. However, the total social costs of the regulation are not expected to change measurably as the higher prices lead to almost no change in the demand for equipment and engines.

Table 10I-10 Fixed Costs Added to Supply Shift in Engine and Equipment Markets[a]

	Base Case (2013)		Shocking Engine and Equipment Markets by Total Costs	
Scenario	**Absolute Change**	**Relative Change (%)**	**Absolute Change**	**Relative Change (%)**
Application Markets				
Price ($/q)	NA	0.02%	NA	0.02%
Quantity (q/yr)	NA	–0.010%	NA	–0.011%
Change in Consumer Surplus ($$10^6$/yr)	$716.1	NA	$796.9	NA
Change in Producer Surplus ($$10^6$/yr)	$515.6	NA	$575.4	NA
Change in Total Surplus ($$10^6$/yr)	$1,231.7	NA	$1,372.3	NA
Equipment Markets				
Price ($/q)	$1,016.49	5.23%	$1,187.23	5.83%
Quantity (units/yr)	–118	–0.014%	–132	–0.016%
Change in Producer Surplus ($$10^6$/yr)	$116.1	NA	$4.6	NA
Engine Markets				
Price ($/q)	$839.71	22.88%	$894.93	24.22%
Quantity (units/yr)	–69	–0.013%	–78	–0.014%
Change in Producer Surplus ($$10^6$/yr)	$30.2	NA	$0.1	NA
Fuel Markets				
Price ($/q)	$0.03	3.09%	$0.03	3.08%
Quantity (gal/yr)	–293,593	–0.014%	–329,511	–0.016%
Change in Producer Surplus ($$10^6$/yr)	$7.8	NA	$8.7	NA
Change in Market Surplus ($$10^6$/yr)	$1,385.7	NA	$1,385.7	NA
NR Spillover	$51.2	NA	$51.2	NA
Operating and Marker Cost ($$10^6$/yr)	–$234.6	NA	–$234.6	NA
Social Costs ($$10^6$/yr)	$1,202.4	NA	$1,202.3	NA

[a] Sensitivity analysis is presented for 2013.

10I.5 Alternative Social Discount Rates

Future benefits and costs are commonly discounted to account for the time value of money. The market and economic impact estimates presented in Section 10.1 calculate the present value of economic impacts using a social discount rate of 3 percent, yielding a total social cost of $16.5 billion. The 3 percent discount rate reflects the commonly used substitution rate of consumption over time. An alternative is the OMB-recommended discount rate of 7 percent that reflects the commonly used real private rate of investment. Table 10I-11 shows the present value calculated over 2004 to 2030 using a 7 percent social discount rate. With the 7 percent social discount rate, the present value of total social costs decreases from $18.9 billion to $9.2 billion.

Table 10I-11. Net Present Values[a]

	NPV (3%)			NPV (7%)		
	Market Surplus (10^6)	**Operating Cost Savings (10^6)**	**Total**	**Market Surplus (10^6)**	**Operating Cost Savings (10^6)**	**Total**
Engine Producers Total	$190.0		$190.0	$135.4		$135.4
Equipment Producers Total	$927.4		$927.4	$595.2		$595.2
Construction Equipment	$433.6		$433.6	$276.2		$276.2
Agricultural Equipment	$306.7		$306.7	$198.0		$198.0
Industrial Equipment	$187.1		$187.1	$120.9		$120.9
Application Total	$17,744.2	–$3,402.4	$14,341.8	$10,066.8	–$2,204.9	$7,861.9
Total Consumer	*$7,450.7*			*$4,222.6*		
Total Producer	*$10,293.5*			*$5,844.1*		
Construction	$6,923.5	–$1,094.9	$5,828.6	$3,895.1	–$709.6	$3,185.6
Agriculture	$5,050.4	–$629.3	$4,421.1	$2,847.5	–$407.8	$2,439.7
Manufacturing	$5,770.3	–$1,678.1	$4,092.2	$3,324.1	–$1,087.5	$2,236.6
Fuel Producers Total	$113.9		$113.9	$64.2		$64.2
PADD 1&3	$52.3		$52.3	$29.5		$29.5
PADD 2	$41.9		$41.9	$23.6		$23.6
PADD 4	$11.5		$11.5	$6.5		$6.5
PADD 5	$8.1		$8.1	$4.6		$4.6
NR Spillover		$886.48			$538.2	
Marker Cost		$63.0			$50.93	
Total	$18,975.5	–$2,452.8	$16,522.7	$10,861.6	–$1,615.8	$9,245.9

[a] Figures are in 2001 dollars.

CHAPTER 11: Small-Business Flexibility Analysis

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CHAPTER 11: Small-Business Flexibility Analysis

This chapter discusses our Initial Regulatory Flexibility Analysis (IRFA) which evaluates the potential impacts of the proposed standards on small entities. The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Pursuant to this requirement, we have prepared an IRFA for the proposed rule. Throughout the process of developing the IRFA, we conducted outreach and held meetings with representatives from the various small entities that could be affected by the rulemaking to gain feedback, including recommendations, on how to reduce the impact of the rule on these entities. The small business recommendations stated here reflect the comments of the small entity representatives (SERs) and members of the Small Business Advocacy Review Panel (SBAR Panel, or 'the Panel').

11.1 Overview of the Regulatory Flexibility Act

In accordance with section 609(b) of the Regulatory Flexibility Act, we convened an SBAR Panel before conducting the IRFA. A summary of the Panel's recommendations is presented in the preamble of this proposed rulemaking. Further, a detailed discussion of the Panel's advice and recommendations is found in the Final Panel Report contained in the docket for this proposed rulemaking.

Section 609(b) of the Regulatory Flexibility Act further directs the Panel to report on the comments of small entity representatives and make findings on issues related to identified elements of the IRFA under section 603 of the Regulatory Flexibility Act. Key elements of an IRFA are:

- a description of and, where feasible, an estimate of the number of small entities to which the proposed rule will apply;
- projected reporting, record keeping, and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirements and the type of professional skills necessary for preparation of the report or record;
- an identification to the extent practicable, of all other relevant Federal rules which may duplicate, overlap, or conflict with the proposed rule;
- any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the proposed rule on small entities.

The Regulatory Flexibility Act was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect those entities. Although we are not required by the Clean Air Act to provide special treatment to small businesses, the Regulatory Flexibility Act requires us to carefully consider the economic impacts that our rules will have on small entities. The recommendations made by the Panel may serve to help lessen these economic impacts on small entities when consistent with Clean Air Act requirements.

11.2 Need for the Rulemaking and Rulemaking Objectives

A detailed discussion on the need for and objectives of this proposed rule are located in the preamble to the proposed rule. As previously stated, controlling emissions from nonroad engines and equipment, in conjunction with diesel fuel quality controls, has important public health and welfare benefits. With the advent of more stringent controls on highway vehicles and their fuels, emissions from nonroad sources, unless controlled, will contribute significantly more harmful pollution than on-highway sources.

Section 213(a)(3) of the Clean Air Act requires EPA to regulate NOx emissions from nonroad engines and vehicles upon an EPA determination that nonroad engines contribute to emissions in a nonattainment area. In part, section 213(a)(3) authorizes EPA to promulgate standards for designated pollutants (including NOx) that require the greatest degree of emission reduction achievable from application of technology to nonroad engines (or vehicles) while giving “appropriate consideration to the cost of applying such technology within the period of time available to manufacturers and to noise, energy, and safety factors associated with the application of such technology.” Section 213(a)(4) applies to all pollutants not specifically identified in section 213(a)(3), and authorizes EPA to promulgate “appropriate” standards for such pollutants, taking into account “costs, noise, safety, and energy factors associated with the application of technology which the Administrator determines will be available” for those engines (or vehicles). Controls on PM implement this provision.

Section 211(c)(1) authorizes EPA to regulate fuels if any emission product of the fuel causes or contributes to air pollution that may endanger public health or welfare, or that may impair the performance of emission control technology on engines and vehicles. We believe that the opportunity for cost-effective emission reductions on a large scale appears to exist.

11.3 Definition and Description of Small Entities

Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the proposed rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration’s (SBA) size standards (see Table 11-1); (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field. Table 11-1 provides an overview of the primary SBA small business categories potentially affected by this regulation.

Table 11-1
Small Business Definitions

Industry	Defined as small entity by SBA if:	Major SIC Codes[a]
Engine manufacturers	Less than 1,000 employees	Major Group 35
Equipment manufacturers:		
- construction equipment	Less than 750 employees	Major Group 35
- industrial truck manufacturers (i.e., forklifts)	Less than 750 employees	Major Group 35
- all other nonroad equipment manufacturers	Less than 500 employees	Major Group 35
Fuel refiners	Less than 1500 employees[b]	2911
Fuel distributors	<varies>	<varies>

[a] Standard Industrial Classification
[b] We have included in past fuels rulemakings a provision that, in order to qualify for the small refiner flexibilities, a refiner must also have a company-wide crude refining capacity of no greater than 155,000 barrels per calendar day. We have included this criterion in the small refiner definition for a nonroad diesel sulfur program as well.

11.3.1 Description of Nonroad Diesel Engine and Equipment Manufacturers

To assess how many engine and equipment manufacturers would directly be affected by the proposed rule which may meet these small entity criteria, we first created a database consisting of firms listed in the Power Systems Research database and compared this with the list of companies from the analysis performed for the 1998 nonroad rulemaking along with membership lists from trade organizations. We then found sales and employment data for the parent companies of these firms using databases such as the Thomas Register and Dun and Bradstreet. Due to the wide variety in the types of equipment which use nonroad diesel engines, there are numerous SIC codes in which the equipment manufacturers report their sales, though the majority of the firms are listed under the SIC major group 35xx- *Industrial and Commercial Machinery and Computer Equipment*.

11.3.2 Description of the Nonroad Diesel Fuel Industry

The analysis that we developed for the refining industry is built on analysis that was performed for the gasoline and highway diesel sulfur programs in recent years. Information about the characteristics of refiners comes from sources including the Energy Information Administration within the U.S. Department of Energy, and from oil industry literature. Our current assessment is that the refining industry is located primarily in SIC 2911. In both the gasoline sulfur and highway diesel sulfur rules, we applied specific small refiner flexibilities to refiners that have no more than 1500 employees and no greater than 155,000 barrels per calendar day crude capacity. For transporters, distributors, and marketers of nonroad diesel fuel, trade groups are the key sources thus far for information about this industry. This industry sector includes several types of businesses that fall into several different SBA small entity criteria; our assessment is that the vast majority of these entities are small.

11.4 Summary of Small Entities to Which the Rulemaking Will Apply

The following sections discuss the small entities - namely nonroad diesel engine manufacturers, nonroad diesel equipment manufacturers, and nonroad fuel refiners and fuel marketers/distributors - directly regulated by this proposed rule. Also, Table 11-2 lists our assessment of the number of small entities that will be directly affected by this rulemaking.

Table 11-2
Number of Small Entities To Which the Nonroad Diesel Rule Will Apply

Industry	Defined as small entity by SBA if:	Number of Affected Entities
Engine manufacturers	Less than 1,000 employees	4[a]
Equipment manufacturers	(see criteria in Table 11-1)	335[a]
Fuel refiners	Less than 1500 employees	26
Fuel distributors	<varies>	see discussion below

[a] The numbers of affected entities for these categories are taken from the total number of companies that were used in our screening analysis (i.e., companies with publicly available employee and sales data).

11.4.1 Nonroad Diesel Engine Manufacturers

We conducted a preliminary industry profile to identify the engine and equipment manufacturers that are in the nonroad diesel sector. We identified more than 1,000 businesses that fit this description; however, due to a lack of publicly available sales or employment data, some of these entities could not be confirmed for consideration in the analysis.

Using information from the preliminary industry profile, we identified a total of 61 engine manufacturers. The top 10 engine manufacturers comprise over 80 percent of the total market, while the other 51 companies make up the remaining percentage.[A] Of the 61 manufacturers, four fit the SBA definition of a small entity. These four manufacturers were Anadolu Motors, Farymann Diesel GmbH, Lister-Petter Group, and V & L Tools (parent company of Wisconsin Motors LLC, formerly 'Wis-Con Total Power'). These businesses comprise approximately 8 percent of the total engine sales for the year 2000.

Wisconsin Motors produces diesel engines for a small niche market and served as a Small Entity Representative (SER) during the Small Business Advocacy Review Panel process, speaking to the needs of small engine manufacturers.

[A] All sales information used for this analysis was 2000 data.

11.4.2 Nonroad Diesel Equipment Manufacturers

The proposed rule may result in equipment manufacturers incurring increased costs as a result of the need to make changes to their equipment to accommodate changes to the engine size and the addition of an aftertreatment package. The vast majority of equipment manufacturers are not integrated companies, meaning that they do not make the engines they install. Thus, most equipment manufacturers are largely dependent on engine manufacturers for the availability of pre-production information about the new engines and for a sufficient supply of the engines once production begins. Equipment manufacturers that are small businesses may, in general, face a disproportionate degree of hardship in adapting to these types of changes in design and increased costs of new, cleaner engines.

To determine the number of equipment manufacturers, we also used the industry profile that was conducted. From this, we identified more than 700 manufacturers with sales and/or employment data that could be included in the screening analysis. These businesses included manufacturers in the construction, agricultural, and outdoor power equipment (mainly, lawn and garden equipment) sectors of the nonroad diesel market. The equipment produced by these manufacturers ranged from small (sub-25 hp walk-behind equipment) to large (in excess of 750 hp, such as mining and construction equipment). Of the manufacturers with available sales *and* employment data (approximately 500 manufacturers), small equipment manufacturers represent 68 percent of total equipment manufacturers (and these manufacturers account for 11 percent of nonroad diesel equipment industry sales). Thus, the majority of the small entities that could potentially experience a significant impact as a result of this rulemaking are in the nonroad equipment manufacturing sector.

11.4.3 Nonroad Diesel Fuel Refiners

Our current assessment is that 26 refiners (collectively owning 33 refineries) meet SBA’s definition of a small business for the refining industry. The 33 refineries appear to meet both of the employee number and production volume criteria mentioned above, out of a total of approximately 91 nonroad refineries. These small refiners currently produce approximately 6 percent of the total high-sulfur diesel fuel. It should be noted that because of the dynamics in the refining industry (e.g., mergers and acquisitions), the actual number of refiners that ultimately qualify for small refiner status under a future nonroad diesel sulfur program could be different from this initial estimate.

11.4.4 Nonroad Diesel Fuel Distributors and Marketers

The industry that transports, distributes, and markets nonroad diesel fuel encompasses a wide range of businesses, including bulk terminals, bulk plants, fuel oil dealers, and diesel fuel trucking operations, and totals thousands of entities that have some role in this activity. More than 90 percent of these entities would meet small entity criteria. Common carrier pipeline companies are also a part of the distribution system; 10 of them are small businesses.

11.5 Related Federal Rules

The proposed certification fees rule, through the Agency's Certification and Compliance Division, may be in place by the time this rule is being implemented, and EPA took this potential cost into consideration when assessing the effects that this rule may have on small businesses.

The fuel regulations that we expect to propose would be similar in many respects to the existing sulfur standard for highway diesel fuel. We are not aware of any area where the regulations under consideration would directly duplicate or overlap with the existing federal, state, or local regulations; however, several small refiners will also be subject to the gasoline sulfur and highway diesel sulfur control requirements, as well as air toxics requirements.

More stringent nonroad diesel sulfur standards may require some refiners to obtain permits from state and local air pollution control agencies under the Clean Air Act's New Source Review program prior to constructing the desulfurization equipment needed to meet the standards.

The Internal Revenue Service has an existing rule that levies taxes on highway diesel fuel only. The rule requires that nonroad diesel (untaxed) fuel be dyed so that regulators and customers will know which type of fuel is which.

11.6 Projected Reporting, Recordkeeping, and Other Compliance Requirements

As with any emission control program, the Agency must have the assurance that the regulated entities will meet the emissions standards and all related provisions. For engine and equipment manufacturers, EPA proposes to continue the reporting, recordkeeping, and compliance requirements prescribed for these categories in 40 CFR part 89. Key among these are certification requirements and provisions related to reporting of production, emissions information, use of transition provisions, etc.

For any fuel control program, EPA must have the assurance that fuel produced by refiners meets the applicable standard, and that the fuel continues to meet the standard as it passes downstream through the distribution system to the ultimate end user. This is particularly important in the case of diesel fuel, where the aftertreatment technologies expected to be used to meet the engine standards under consideration are highly sensitive to sulfur. The recordkeeping, reporting and compliance provisions of the proposed rule are fairly consistent with those currently in place for other fuel programs, including the current 15 ppm highway diesel regulation. For example, recordkeeping involves the use of product transfer documents, which are already required under the 15 ppm highway diesel sulfur rule.

11.7 Projected Economic Effects of the Proposed Rulemaking

The projected costs of the rulemaking on a per engine basis were independent of the size of the engine or equipment manufacturer. A full discussion of these costs, and the corresponding methodology, is located in Chapter 6 of this Draft RIA. Of the 710 entities with publicly available sales data, our screening analysis found that the average total annual compliance costs would be $33,000 per small entity and $4.42 million per large entity. Further, a cost-to-sales ratio test, a ratio of the estimated annualized compliance costs to the value of sales per company, was performed for these entities.[B] We found that approximately 4 percent (13 companies) of small entities in the engine and equipment manufacturing industry were affected between 1 and 3 percent of sales (i.e., the estimated costs of compliance with the proposed rule would be greater than 1 percent, but less than 3 percent, of their sales). 1 percent (4 companies) of small entities were affected at greater than 3 percent. In all, 17 of the 518 potentially affected small engine and equipment manufacturers are estimated to have compliance costs that could exceed 1 percent of their sales.

Based on our outreach, fact-finding, and analysis of the potential impacts of our regulations on small businesses, the Panel concluded that small refiners in general would likely experience a significant and disproportionate financial hardship in reaching the objectives of the proposed nonroad diesel fuel sulfur program. One indication of this disproportionate hardship for small refiners is the relatively high cost per gallon projected for producing nonroad diesel fuel under the proposed program. Refinery modeling (of all refineries), indicates significantly higher refining costs for small refiners. Specifically, we project that without special provisions, refining costs for small refiners on average would be about 5.5 cents per gallon compared to about 4.0 cents per gallon for non-small refiners. Chapter 7 of this Draft RIA further discusses the estimated costs of production and distribution of low sulfur fuels.

The majority of the fuel-related cost of the proposal is refining-related, with only 15-25 percent of the costs being distribution-related. The proposed allowance that highway and off-highway diesel engine fuel meeting the same sulfur specification can be shipped fungibly until it leaves the terminal obviates the need for additional storage tankage in this segment of the distribution system.[C] The proposed rule would also allow 500 ppm off-highway diesel engine fuel to be mixed with high-sulfur diesel fuel once the fuels are dyed to meet IRS requirements. This provision would ease the last part of the distribution of high-sulfur nonroad, locomotive, and marine (NRLM) diesel fuel.

[B] The cost-to-sales ratio test assumes that control costs are completely absorbed by each entity and does not account for or consider interaction between manufacturers/producers and consumers in a market context.

[C] Including the refinery, pipeline, marine tanker, and barge segments of the distribution system.

For a complete discussion of the economic impacts of the proposed rulemaking, see Chapter 10, the economic impact analysis chapter, of this Draft RIA.

11.8 Regulatory Alternatives

The Panel's findings and discussions are based on the information that was available during the term of the Panel and issues that were raised by the SERs during the outreach meetings and in their written comments. It was agreed that EPA should consider the issues raised by the SERs (and issues raised in the course of the Panel) and that EPA should consider the comments on flexibility alternatives that would help to mitigate any negative impacts on small businesses. Alternatives discussed throughout the Panel process include those offered in the development of the upcoming rule. Though some of the recommended flexibilities may be appropriate to apply to all entities affected by the rulemaking, the Panel's discussions and recommendations are focused mainly on the impacts, and ways to mitigate adverse impacts, on small businesses. A summary of the Panel's recommendations, along with those provisions that we are actually proposing in this action, are detailed below. A full discussion of the regulatory alternatives and hardship provisions discussed and recommended by the Panel, all written comments received from SERs, and summaries of the two outreach meetings that were held with the SERs can be found in the SBREFA Final Panel Report.[1] In addition, all of the flexibilities (or 'transition provisions') that were proposed in the rulemaking for small businesses, as well as those for all entities that may be affected by the rulemaking, are described in the preamble to the proposed rule.

11.8.1 Small Engine Manufacturers

The Panel developed a wide range of regulatory alternatives to mitigate the impacts of the rulemaking on small businesses, and recommended that we propose and seek comment on the flexibilities. Described below are the flexibility options recommended by the Panel, along with alternatives that were suggested by some individual Panel members, and our proposed regulatory alternatives.

11.8.1.1 Flexibility Alternatives for Small Engine Manufacturers

11.8.1.1.1 SBAR Panel Recommendations

Based on the recommendations of the Panel, the transition flexibilities that were under consideration were dependent upon what approach, or approaches, we proposed for the rulemaking. Further, each manufacturer would be limited to 2,500 units per year (to allow for some market growth). The proposed transition provisions are:

1. For an approach with two phases of standards the Panel recommended that:
   - an engine manufacturer could skip the first phase and comply on time with the second; or,

  - a manufacturer could delay compliance with each phase of standards for up to two years.

2. For an approach that entails only one phase of standards, the manufacturer could opt to delay compliance. The Panel recommended that the length of the delay be a three-year period; the Panel also recommended that we take comment on whether this delay period should be two, three, or four years. Each delay would be pollutant-specific (i.e., the delay would apply to each pollutant as it is phased in).

All Panel members believed that the aforementioned options would offer an opportunity to reduce the burden on small manufacturers while at the same time meeting the regulatory goals of the Agency. Further, the we believe that these options will not put small manufacturers at a significant disadvantage as they will be in compliance with the Tier 4 standards in the long run and the flexibility options will give them more lead time to comply.

11.8.1.1.2 EPA's Proposed Regulatory Alternatives

We feel that a complete exemption from the upcoming standards (even assuming that such an exemption could be justified legally) would put these manufacturers at a competitive disadvantage as the rest of the market will be producing compliant engines and only equipment able to accommodate compliant engines will be saleable. Due to the structure of the standards and their timing, as discussed in Section III of the preamble to the proposed rulemaking, we are proposing regulatory alternatives, or transition provisions, for small engine manufacturers which encompass both approaches recommended by the Panel (with the inclusion of the 2,500 unit limit for each manufacturer).

- With regard to PM:
  - Engines under 25 hp, and those between 75 and 175 hp, have only one standard so the manufacturer could delay compliance with these standards for up to three years. Based on available data, we believe that there are no small manufacturers of nonroad diesel engines above 175 hp.
  - For engines between 50 and 75 hp, we are proposing a one phase program with the option to delay compliance for one year if interim standards are met. For this power category we are treating the PM standard as a two phase standard with the stipulation that small manufacturers cannot use PM credits to meet the interim standard. Furthermore, if a small manufacturer elects the optional approach to the standard (i.e., opts to skip the interim standard), no further relief will be provided. See Section III of the preamble to the proposed rulemaking for further detail on the PM standards for engine manufacturers.
- With regard to NOx:
  - There is no change in the NOx standard for engines under 25 hp and those between 50 and 75 hp, therefore, we are not proposing special provisions for these two power bands.
  - For engines in the 25-50 hp and the 75-175 hp categories we are proposing a three year delay in the program consistent with the one-phase approach recommendation

above. Again, based on available data, we believe that there are no small manufacturers of nonroad diesel engines above 175 hp.

11.8.1.2 Hardship Provisions for Small Engine Manufacturers

11.8.1.2.1 SBAR Panel Recommendations

The Panel recommended that two types of hardship provisions be extended to small engine manufacturers. These provisions are:

1. For the case of a catastrophic event, or other extreme unforseen circumstances, beyond the control of the manufacturer that could not have been avoided with reasonable discretion (i.e., fire, tornado, supplier not fulfilling contract, etc.); and

2. For the case where a manufacturer has taken all reasonable business, technical, and economic steps to comply but cannot do so.

Either relief provision could provide lead time for up to 2 years—in addition to the flexibilities listed above in Section 11.8.1.1—and a manufacturer would have to demonstrate to the Agency's satisfaction that failure to sell the noncompliant engines would jeopardize the company's solvency. The Panel further recommended that the Agency may require that the manufacturer make up the lost environmental benefit through the use of programs such as supplemental environmental projects.

For the flexibilities listed above, the Panel recommended that engine manufacturers and importers must have certified engines in model year 2002 or earlier in order to take advantage of these provisions. Each manufacturer would be limited to 2,500 units per year (to allow for some market growth). These provisions were recommended by the Panel in order to prohibit the misuse of these flexibilities as a tool to enter the nonroad diesel market or to gain unfair market position relative to other manufacturers.

11.8.1.2.2 EPA's Proposed Hardship Provisions

We are proposing to adopt the Panel recommendations for hardship provisions for small engine manufacturers. While perhaps ultimately not necessary given the phase-in schedule discussed above, we believe that such provisions provide a useful safety valve in the event of unforeseen extreme hardship.

11.8.1.3 Other Small Engine Manufacturer Issues

11.8.1.3.1 SBAR Panel Recommendations

It was also recommended by the Panel that an emission-credit program of averaging, banking, and trading (ABT) be included as part of the overall rulemaking program.

11.8.1.3.2 EPA's Proposal

As discussed in Section VII of the preamble to this proposal, we are indeed proposing ABT provisions. ABT is being proposed as it is intended to enhance the flexibility offered to engine manufacturers that will be of assistance in making the transition to meet the stringent standards in this proposed rule in the leadtime proposed. As noted in Section VII.A, we are proposing to retain the basic structure of the current nonroad diesel ABT program, though a number of changes (which will help to accommodate implementation of the proposed emission standards) are being proposed with this action.

Though the Panel recommended small engine manufacturer-specific ABT provisions, such provisions are not being included in this proposal. We do not believe it would be appropriate to provide a different ABT program for small engine manufacturers, especially given the special provisions that are proposed above. Discussions during the SBAR process indicated that small volume manufacturers would need extra time to comply due to cost and personnel constraints, and there is little reason to believe that small manufacturer specific ABT provisions could create an incentive to accelerate compliance. Small manufacturers would of course be able to participate in the general ABT program.

11.8.1.4 SBA Office of Advocacy Observations

11.8.1.4.1 What One Panel Member Observed

The SBA Chief Counsel for the Office of Advocacy offered some observations about the impacts of the regulatory approaches on affected small engine and equipment manufacturers. While the other Panel members did not join in these observations, the Panel recommended that the Administrator carefully consider these points and examine further the factual, legal and policy questions raised here in developing the proposed rule. First, given the available information, the Office of Advocacy stated that they had substantial doubts about the technical feasibility and cost of engineering aftertreatment devices into a wide diversity of nonroad diesel applications for engines less than 50 kilowatts (70 hp). They stated that considerable concern has been raised regarding the technical feasibility of aftertreatment devices, even for larger engines, and particularly in the case of NOx adsorbers. Second, the low retail cost and low annual production for many of these applications make it extremely difficult for the equipment manufacturer to absorb these additional costs. Third, Advocacy believes that given the small size of these engines, and the typically small useful life, and the fact that these engines are already subject to Tier 2 regulations, the environmental reductions attributable to such engines would be relatively small. The Office of Advocacy believes that, based on the available information, the Agency does not have a sufficient basis to move forward with a proposal that would require nonroad engines under 50 kilowatts to use aftertreatment devices.

Based on the SERs' concerns about the technical feasibility of the Tier 4 standards, and the technical information discussed in the Panel report, SBA recommended that we include a technological review of the standards in the 2008 timeframe in the rulemaking proposal. The Panel recommended that we consider this recommendation.

11.8.1.4.2 EPA's Observations

SBA Office of Advocacy stated that considerable concern has been raised regarding the technical feasibility of PM and NOx aftertreatment devices, particularly in the case of NOx adsorbers. As explained in the preamble, we have found no factual basis for this statement with respect to PM controls based on use of advanced aftertreatment for engines between 25 and 75 hp. We are not proposing standards based on performance of advanced aftertreatment for engines under 25 hp, and for NOx, for engines 75 hp and under.

With respect to the PM standards for these engines, however, EPA disagrees with the statement made by the Office of Advocacy that, based on available information, we do not have a sufficient basis to move forward with this proposed rulemaking requiring nonroad engines under 50 kW to use aftertreatment devices. As we have documented in the preamble and elsewhere in this Draft RIA, EPA believes that the standards for PM for engines in these power ranges are feasible at reasonable cost, and will help to improve very important air quality problems, especially by reducing exposure to diesel PM and by aiding in attainment of the PM 2.5 National Ambient Air Quality Standards (NAAQS). Indeed, given these facts, EPA is skeptical that an alternative of no PM standards for these engines would be appropriate under section 213 (a) (4). Moreover, the statement regarding cost impacts fails to account for transition flexibilities provided all equipment manufacturers as part of the proposal.

11.8.2 Nonroad Diesel Equipment Manufacturers

11.8.2.1 Flexibility Alternatives for Small Equipment Manufacturers

11.8.2.1.1 SBAR Panel Recommendations

The Panel recommended that we propose to continue the transition provisions offered for the Tier 1 and Tier 2 nonroad diesel emission standards, as set out in 40 CFR 89.102, with some potential modifications. The recommended transition provisions for small manufacturers are:

1. Percent-of-Production Allowance: Over a seven model year period, equipment manufacturers may install engines not certified to the new emission standards in an amount of equipment equivalent to 80 percent of one year's production. This is to be implemented by power category with the average determined over the period in which the flexibility is used.

2. Small Volume Allowance: A manufacturer may exceed the 80 percent allowance in seven years as described above, provided that the previous Tier engine use does not exceed 700 total over seven years, and 200 in any given year. This is limited to one family per power category. Alternatively, the Panel also recommended, at the manufacturer's choice by hp

category, a program that eliminates the “single family provision” restriction with revised total and annual sales limits as shown below:

- For categories ≤175 hp - 525 previous Tier engines (over 7 years) with an annual cap of 150 units (these engine numbers are separate for each hp category defined in the regulations).
- For categories of > 175hp - 350 previous Tier engines (over 7 years) with an annual cap of 100 units (these engine numbers are separate for each hp category defined in the regulations).

The Panel recommended that we seek comment on the total number of engines and annual cap values listed above. In contrast to the Tier 2/Tier3 rule promulgated in 1998, SBA expects the transition to the Tier 4 technology will be more costly and technically difficult. Therefore, the small equipment manufacturers may need more liberal flexibility allowances especially for equipment using the lower hp engines. The Panel’s recommended flexibility may not adequately address the approximately 50 percent of small business equipment models where the annual sales per model is less than 300 and the fixed costs are higher. Thus, SBA and OMB recommended that we seek comment on implementing the small volume allowance (700 engine provision) for small equipment manufacturers without a limit on the number of engine families which could be covered in any hp category.

3. In addition, due to the changing nature of the technology as the manufacturers transition from Tier 2 to Tier 3 and Tier 4, the Panel recommended that the equipment manufacturers be permitted to borrow from the Tier3/Tier 4 flexibilities for use in the Tier 2/Tier 3 time frame.

To maximize the likelihood that the application of these flexibilities will result in the availability of previous Tier engines for use by the small equipment manufacturers, the Panel recommended that - similar to the application of flexibility options that are currently in place - these three flexibilities should be provided to all equipment manufacturers. (See discussion on transition provisions for all equipment manufacturers in Section VII.B of the proposed rule preamble.)

An issue was raised that we establish a provision which would allow manufacturers to request limited “application specific” alternative standards for equipment configurations which present unusually challenging technical issues for compliance. The three flexibilities recommended above would provide latitude, at least in the near term, and a properly structured emission-credit program for the engine manufacturers would provide long-term latitude. Even if one were to assume that these flexibilities provide insufficient leeway (which may not be the case), application specific standards would still be cumbersome for both the small equipment manufacturers and for the Agency. Nonetheless, the Panel recommended that we seek comment on the need for and value of special application specific standards for small equipment manufacturers.

11.8.2.1.2 EPA's Proposed Regulatory Alternatives

We are in fact proposing the Percent-of-Production and Small Volume Allowances for all equipment manufacturers, and explicitly took the Panel report into account in making that proposal (see Section VII.B of the preamble). We believe that this proposal should provide the type of transition leeway recommended by the Panel. We believe that the transition provisions could allow small equipment manufacturers to postpone any redesign needed on low sales volume or difficult equipment packages, thus saving both money and strain on limited engineering staffs. Within limits, small equipment manufacturers would be able to continue to use their current engine/equipment configuration and avoid out-of-cycle equipment redesign until the allowances are exhausted or the time limit passes.

In regards to the Panel's suggested exemption and annual cap values listed above, we have requested comment on both of these elements in Section VII.B of the preamble to the proposed rule. We have also requested comment on implementing the small volume allowance provision without the single family limit provision using caps slightly lower than 700 units, with this provision being applied separately to each engine power category subject to the proposed standards.

Similar to the discussion in Section VII.B of the proposed rule preamble, we are requesting comment on new proposed requirements associated with the use of transition provisions by foreign importers. During the SBREFA Panel process, the Panel discussed the possible misuse of the transition provisions by using them as a loophole to enter the nonroad diesel equipment market or to gain unfair market position relative to other manufacturers. The Panel recognized that this was a possible problem, and believed that the requirement that small equipment manufacturers and importers have reported equipment sales using certified engines in model year 2002 or earlier was sufficient to alleviate this problem. Upon further analysis, EPA found that importers of equipment from a foreign equipment manufacturer could as a group import more excepted equipment from that foreign manufacturer than 80 percent of that manufacturer's production for the US market or more than the small volume allowances identified in the transition provisions. This also creates a potentially significant disparity between the treatment of foreign and domestic equipment manufacturers. We did not intend this outcome, and we do not believe that it is needed to provide reasonable leadtime to foreign equipment manufacturers.

The purpose of these transition provisions is to lessen the burden on small equipment manufacturers. Therefore, we are requesting comment on the additional requirement that only the small nonroad diesel equipment manufacturer that is most responsible for the manufacturing and assembling process, and therefore the burden of complying with the proposed standards, would qualify for the allowances provided under the small equipment manufacturer transition provisions. Under this requirement, only a small importer that produces or manufactures nonroad diesel equipment would be eligible for these transition provisions. A small importer that does not manufacture or produce equipment does not face a burden in complying with the proposed standard, and therefore would not receive any allowances under these transition provisions directly, but could import exempt equipment if it is covered by an allowance or transition provisions associated with a foreign small equipment manufacturer. We believe that this requirement transfers the flexibility offered in these transition provisions to the party with the burden and would allow transition provisions and allowances to be used by foreign small equipment manufacturers in the same way as domestic small equipment manufacturers, while avoiding the potential for misuse by importers of unnecessary allowances.

We are also proposing the Panel's recommendation that equipment manufacturers be allowed to borrow from Tier 4 flexibilities in the Tier2/3 timeframe. See the more extended discussion on this issue in Section VII.B of the preamble.

With regard to the Panel recommendation for a provision allowing small manufacturers to request limited "application specific" alternative standards for equipment configurations which present unusually challenging technical issues for compliance, we have requested comment on this recommendation (in Section VII.C of the preamble to the proposed rule). We believe that the need for such a provision has not been established and putting it forth without more information could provide more lead time than can be justified, and could undermine emission reductions which are achievable. Moreover, no participant in the SBAR process offered any empirical support that such a problem even exists. Nor have such issues been demonstrated (or raised) by equipment manufacturers, small or large, in implementing the current nonroad standards. Further, we believe that any application-specific difficulties can be accommodated by the transition provisions the Agency is proposing including ABT. Nonetheless, in keeping with the SBAR recommendations, we have requested comment on the value of, and need for, special application specific standards for small equipment manufacturers in the preamble.

11.8.2.2 Hardship Provisions for Small Equipment Manufacturers

11.8.2.2.1 SBAR Panel Recommendations

The Panel also recommended that two types of hardship provisions be extended to small equipment manufacturers. These provisions are:

1. For the case of a catastrophic event, or other extreme unforseen circumstances, beyond the control of the manufacturer that could not have been avoided with reasonable discretion (i.e., fire, tornado, supplier not fulfilling contract, etc.); and

2. For the case where a manufacturer has taken all reasonable business, technical, and economic steps to comply but cannot. In this case relief would have to be sought before there is imminent jeopardy that a manufacturer's equipment could not be sold and a manufacturer would have to demonstrate to the Agency's satisfaction that failure to get permission to sell equipment with a previous Tier engine would create a serious economic hardship. Hardship relief of this nature cannot be sought by a manufacturer which also manufactures the engines for its equipment.

11.8.2.2.2 EPA's Proposed Hardship Provisions

We are proposing that the Panel recommended hardship provisions be extended to small equipment manufacturers in addition to the transition provisions described above. To be eligible for these hardship provisions (as well as for the proposed transition provisions), equipment manufacturers and importers must have reported equipment sales using certified engines in model year 2002 or earlier. As explained earlier (and also in Sections VII.B and VII.C of the preamble to the proposed rule), this proposal is needed to thwart misuse of these provisions as a loophole to enter the nonroad diesel equipment market or to gain unfair market position relative to other manufacturers and we request comment on this restriction.

As explained earlier in Section VII.B of the preamble to the proposed rule, hardship relief would not be available until other allowances have been exhausted. Either relief provision would provide additional lead time for small equipment manufacturers for up to two model years based on the circumstances, but we may require recovery of the lost environmental benefit.

11.8.3 Nonroad Diesel Fuel Refiners

11.8.3.1 Flexibility Alternatives for Small Fuel Refiners

11.8.3.1.1 SBAR Panel Recommendations

The Panel considered a range of options and regulatory alternatives for providing small refiners with flexibility in complying with new sulfur standards for nonroad diesel fuel. Taking into consideration the comments received on these ideas during the Panel process, as well as additional business and technical information gathered about potentially affected small entities, the Panel recommended that whether we propose a one-step or a two-step approach, we should provide for delayed compliance for small refiners as shown in Table 11-3 below.

Table 11-3
SBREFA Panel Small Refiner Options Under
Potential 1-Step and 2-Step Nonroad Diesel Base Programs
Recommended Sulfur Standards (in parts per million, ppm) [a]

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015+
Under 1-Step Program										
Non-Small [b]	--	--	15	15	15	15	15	15	15	15
Small	--	--	--	–	–	–	15	15	15	15
Under 2-Step Program										
Non-Small [c]	--	500	500	500	15	15	15	15	15	15
Small	--	--	--	--	500	500	500	500	15	15

[a] New standards are assumed to take effect June 1 of the applicable year.

[b] Assumes 500 ppm standard for marine + locomotive fuel for non-small refiners for 2008, and for small refiners for 2012 and later.

[c] Assumes 500 ppm standard for marine + locomotive fuel for non-small refiners for 2007, and for small refiners for 2010 and later.

11.8.3.1.2 EPA's Proposed Regulatory Alternatives

We have continued to consider the issues raised during the SBREFA process and have decided to propose each of the flexibility provisions recommended by the Panel. Because we are proposing in this rule a two-step approach to fuel implementation, we are thus proposing the small refiner relief provisions as recommended by the Panel for a two-step program, which are shown in Table 11-4 below.

Table 11-4
Small Refiner Options 2-Step Nonroad Diesel Base Programs
Recommended Sulfur Standards (in parts per million (ppm))[a]

Under 2-Step Program	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015+
Non-Small[b]	—	500	500	500	15	15	15	15	15	15
Small	—	—	—	—	500	500	500	500	15	15

[a] New standards are assumed to take effect June 1 of the applicable year.

[b] Assumes 500 ppm standard for marine + locomotive fuel for non-small refiners for 2007 and later and for small refiners for 2010 and later.

Generally, we have structured these proposed provisions to address small refiner hardship while expeditiously achieving air quality benefits and ensuring that the availability of 15 ppm nonroad diesel fuel would coincide with the introduction of 2011 model year nonroad diesel engines and equipment. The following paragraphs review the reasons we believe that the special provisions for small refiners recommended by the Panel are necessary and appropriate.

First, the proposed compliance schedule for the nonroad diesel program, combined with flexibility for small refiners, would achieve the air quality benefits of the program as soon as possible, while helping to ensure that small refiners will have adequate time to raise capital for new or upgraded fuel desulfurization equipment. Most small refiners have limited additional sources of income beyond refinery earnings for financing and typically do not have the financial backing that larger and generally more integrated companies have. Therefore, they can benefit from additional time to accumulate capital internally or to secure capital financing from lenders.

Second, we recognize that while the sulfur levels in the proposed program can be achieved using conventional refining technologies, new technologies are also being developed that may reduce the capital and/or operational costs of sulfur removal. Thus, we believe that allowing small refiners some additional time for newer technologies to be proven out by other refiners would have the added benefit of reducing the risks faced by small refiners. The added time would likely allow for lower costs of these improvements in desulfurization technology (e.g., better catalyst technology or lower-pressure hydrotreater technology). This would help to offset the disproportionate financial burden facing small refiners.

Third, providing small refiners more time to comply would increase the availability of engineering and construction resources. Most refiners would need to install additional processing equipment to meet the nonroad diesel sulfur requirements. We anticipate that there may be significant competition for technology services, engineering resources, and construction management and labor. In addition, vendors will be more likely to contract their services with the larger refiners first, as their projects will offer larger profits for the vendors. Temporarily delaying compliance for small refiners would spread out the demand for these resources and probably reduce any cost premiums caused by limited supply.

We have also requested comment on a slightly different compliance schedule that would require small refiners to produce 15 ppm nonroad diesel fuel beginning June 1, 2013, one year earlier than proposed above. Such a schedule would align the end of the interim small refiner provisions with the end of the proposed phase-in for nonroad engines and equipment and eliminate higher sulfur nonroad fuel from the distribution system by the time all new engines required 15 ppm fuel.

11.8.3.2 Small Refiner Incentives for Early Compliance

11.8.3.2.1 SBAR Panel Recommendations

The SBAR Panel also recommended that we propose certain provisions to encourage early compliance with lower sulfur standards. The Panel recommended that we propose that small refiners be eligible to select one of the two following options:

1. Credits for Early Desulfurization: The Panel recommended that we propose, as part of an overall trading program, a credit trading system that allows small refiners to generate and sell credits for nonroad diesel fuel that meets the small refiner standards earlier than that required in the above table. Such credits could be used to offset higher sulfur fuel produced by that refiner or by another refiner that purchases the credits.

2. Limited Relief on Small Refiner Interim Gasoline Sulfur Standards: The Panel recommended that a small refiner producing its entire nonroad diesel fuel pool at 15 ppm sulfur by June 1, 2006, and that chooses not to generate nonroad credits for its early compliance, receive a 20 percent relaxation in its assigned small refiner interim gasoline sulfur standards. However, the Panel recommended that the maximum per-gallon sulfur cap for any small refiner remain at 450 ppm.

11.8.3.2.2 EPA's Proposal

We agree with the Panel recommendation of encouraging early compliance with the standards. Some small refiners have indicated that they might find it necessary to produce fuel meeting the nonroad diesel sulfur standards earlier than they would be required to under the small refiner program described above, for a variety of reasons: some small refiners could find that their distribution systems limit the number of grades of diesel fuel that will be carried; others might find it economically advantageous to make 500 ppm or 15 ppm fuel earlier so as not to lose market share; and one small refiner indicated that it could decide to desulfurize its nonroad pool at the same time as its highway diesel fuel, in June of 2006 (due to limitations in its distribution system and to take advantage of economies of scale). Given these situations, we are proposing that small refiners be able to choose between the two mutually exclusive options, as recommended by the Panel, to provide incentives for early compliance.

More specifically, with the first option a small refiner could generate NRLM diesel sulfur credits for production of 500 ppm NRLM diesel fuel prior to June 1, 2010, and for production of 15 ppm nonroad fuel from June 1, 2010 through May 31, 2012. The specifics of the overall credit program, including how they would be applicable to small refiners, are described in Section IV of the proposed rulemaking preamble.

A refiner that qualifies for the second option could receive a modest revision in its interim small refiner gasoline sulfur standards, starting January 1, 2004. Specifically, the applicable small refiner annual average and per-gallon cap gasoline standards would be revised upward by

20 percent for the duration of the small refiner gasoline sulfur interim program (i.e., through either 2007 or 2010, depending on whether the refiner had extended its participation in the gasoline sulfur interim program by complying with the highway diesel standard at the beginning of that program (June, 2006, as provided in 40 CFR 80.552(c))). However, as recommended by the Panel, in no case could the per-gallon cap exceed 450 ppm, the highest level allowed under the gasoline sulfur program.

We believe it is very important to link any such temporary relaxation of a small refiner gasoline sulfur interim sulfur standards with environmental benefit of early desulfurization of a significant volume of nonroad diesel fuel. Thus, we are proposing that a small refiner wishing to use the second option produce a minimum volume of nonroad diesel fuel at 15 ppm by June 1, 2006. Each participating small refiner would need to produce a volume of 15 ppm fuel that was at least 85 percent of the volume represented by its non-highway distillate baseline percentage. If the refiner began to produce gasoline in 2004 at the higher interim standard of this provision but then either failed to meet the 15 ppm standard for its nonroad fuel or failed to meet the 85 percent minimum volume requirement, the original small refiner interim gasoline sulfur standard applicable to that refiner would be reinstated. In addition, the refiner would need to compensate for the higher gasoline levels that it had enjoyed by purchasing gasoline sulfur credits or producing an equivalent volume of gasoline below the required sulfur levels. These compensation provisions are discussed further in Section VIII of the preamble. Under this option, a small refiner could in effect shift some funds from its gasoline sulfur program to accelerate desulfurization of nonroad diesel fuel. Given the environmental benefit that would result from the production of 15 ppm fuel earlier than necessary, and the small potential loss of emission reduction under the gasoline sulfur program from fuel produced by the very few small refiners that we believe would qualify under this second option, we believe the environmental impact of this option would be neutral or positive.

11.8.3.3 Hardship Provisions for Small Fuel Refiners

11.8.3.3.1 SBAR Panel Recommendations

The Panel recommended that we propose refiner hardship provisions modeled after those established under the gasoline sulfur and highway diesel fuel sulfur program (see 40 CFR 80.270 and 80.560). Specifically, the Panel recommended that we propose a process that, like the hardship provisions of the gasoline and highway diesel rules, allows refiners to seek case-by-case approval of applications for temporary waivers to the nonroad diesel sulfur standards, based on a demonstration to the Agency of extreme hardship circumstances. This provision would allow domestic and foreign refiners, including small refiners, to request additional flexibility based on a showing of unusual circumstances that result in extreme hardship and significantly affect the ability of the refiner to comply by the applicable date, despite its best efforts.

11.8.3.3.2 EPA's Proposed Hardship Provisions

We believe that providing short-term relief to those refiners that need additional time because they face hardship circumstances facilitates adoption of an overall program that reduces NRLM diesel fuel sulfur to 500 ppm beginning in 2007, and nonroad diesel fuel sulfur to 15 ppm in 2010, for the majority of the industry.

11.8.4 Nonroad Diesel Fuel Distributors and Marketers

The diesel fuel approach being considered by the Agency includes the possibility of there being two grades of nonroad diesel fuel (500/15 ppm) in the market place for at least a transition period. The distributors support a one-step approach because it has no significant impact on their operations. The distributors offered some suggestions on how they might deal with this issue, but indicated that there would be adverse impacts in some circumstances. The Panel recommended that we study this issue further. Chapter 7 of this Draft Regulatory Impact Analysis further discusses costs and related issues relevant to fuel distributors under our proposed program.

We have designed the proposed fuel sulfur program to minimize the need for additional product segregation and the associated feasibility and cost issues for fuel distributors associated with it. Beyond the accommodation of fuel distributor concerns during the overall design of the fuel program, it is not possible for us to provide special provisions for particular (i.e., small) fuel distributors to limit the potential impact of the proposed rule. The benefits of the proposed low sulfur diesel program can only be achieved if the volume of diesel fuel consumed by NRLM engines is matched by the production and distribution of at least the same volume of diesel fuel produced to the appropriate low sulfur levels. The proposed program must also ensure sufficient availability of 15 ppm diesel fuel for use in nonroad engines in 2010 and not compromise the availability needs for 15 ppm diesel fuel for use in highway diesel engines under the highway diesel program, which begins in 2006. Thus, the low sulfur diesel fuel that we are proposing that refiners produce would need to be carried through the fuel distribution system to the end-user.

In order to allow for a smooth and orderly transition of diesel fuel in the distribution system to 15 ppm, we are proposing that parties downstream of the refineries be allowed a small amount of additional time to turnover their tanks to 15 ppm. We are proposing that at the terminal level, nonroad diesel fuel would be required to meet the 15 ppm sulfur standard beginning July 15, 2010. At bulk plants, wholesale purchaser-consumers, and any retail stations carrying nonroad diesel, this fuel would have to meet the 15 ppm sulfur standard by September 1, 2010. The proposed transition schedule for compliance with the 15 ppm standard at refineries, terminals, and secondary distributors are the same as those allowed under the recently promulgated highway diesel fuel program.

Further, to avoid the costs associated with segregating 500 ppm NRLM diesel fuel from 500 ppm highway fuel, we are proposing that the existing requirement that NRLM diesel fuel be dyed leaving the refinery would need to be made voluntary. This is discussed in Section 11.7 of this Draft RIA.

Chapter 11 References

1. Final Panel Report of the Small Business Advocacy Review Panel on EPA's Proposed Rule-Control of Emission of Air Pollution From Land-Based Nonroad Compression Ignition Engines, December 23, 2002.

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CHAPTER 12: Regulatory Alternatives

Our proposed program represents a combination of engine and fuel standards and their associated timing that we believe to be superior to the alternatives considered given feasibility, cost, and environmental impact. In this chapter we present and discuss the alternative program options that we evaluated in order to make this determination. These alternatives are cast as twelve specific Program Options.

For each Option, we first present a full description of the level and timing of fuel and engine standards. We then present the emissions inventory impacts associated with each Option in comparison to our proposed program, as well as the monetized health and welfare benefits, costs, and cost-effectiveness. Finally, we present our assessment of the rationale, feasibility, and issues associated with each Option in light of the analyses we conducted.

12.1 Range of Options Considered

Our proposed emission control program consists of a two-step program to reduce the sulfur content of nonroad diesel fuel in conjunction with the NOx and PM engine standards. During the development of our program, we also considered a one-step fuel program wherein all sulfur reductions in the diesel fuel occur in a single step. Since the fuel provisions and timing dictate to a large extent the possible engine standards, we have structured this section to first discuss issues of variations in the fuel program. Thus, the Program Options are divided into One-Step and Two-Step options, to highlight the fuel sulfur program and its driving impact on the engine standards. Within each of these fuel program approaches, we considered several variations and combinations with engine standards.

This section provides only a description of what the program options are. Subsequent sections present the inventory impacts, benefits, costs, and cost-effectiveness. Finally, Section 12.6 summarizes the rationale for each option and our evaluation of the issues and feasibility associated with the options.

12.1.1 One-Step Options

One-step options are those in which the fuel sulfur standard is applied in a single step; there are no phase-ins or step changes. In all one-step options, the transient test cycle is required concurrently with the introduction of the transitional Tier 4 engine standards in any horsepower group.

Option 1a differs from Options 1 and 1b in terms of the engine standards and their associated timing. Because so much time was needed to produce benefits estimates, EPA decided early in the program development process to use this option as the basis of our benefits analysis (although EPA ultimately determined not to propose this option). Option 1b differs from Option 1 only in the timing of the fuel sulfur standard, and is intended to generate additional early sulfate PM reductions. As a result, we did not lower the certification fuel sulfur level to 15ppm in 2007 and 2008 when modeling this Option, since doing so would permit manufacturers to take advantage of the lower sulfur and thus reduce the PM reductions associated with their certified engines.

The one-step options are summarized in Table 12.1.1-1. Following this table is a summary of the existing Tier 1, Tier 2, and Tier 3 standards from 40 CFR §89.112 that form the baseline of our analyses. The specifics of the three one-step options are shown in the standard charts in Figures 12.1.1-2, 3, and 4. Only changes to the standards are shown in these three figures, i.e. if no new standard for a given pollutant is indicated, the previous standard applies.

Table 12.1.1-1
Summary of One-Step Options

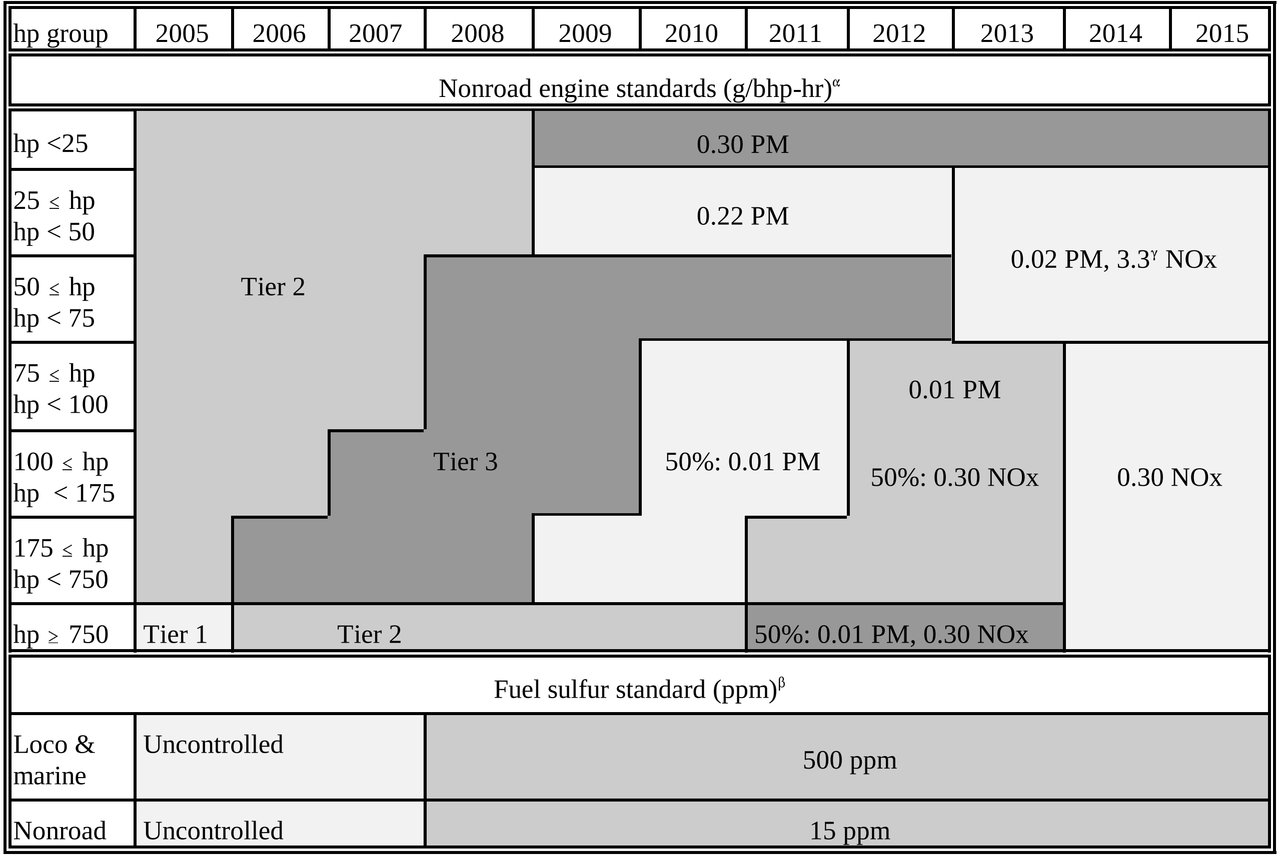
Option	Summary Description
Option 1	• Fuel sulfur ≤ 15ppm in June 2008 for nonroad, ≤ 500ppm for locomotives and marine engines • <50 hp: PM stds only in 2009 • 25-75 hp: PM aftertreatment-based standards and EGR or equivalent NOx technology in 2013; no NOx aftertreatment • >75 hp: PM aftertreatment-based standards phasing in beginning in 2009; NOx aftertreatment-based standards phasing in beginning in 2011 *See Figure 12.1.1-2*
Option 1a	• Fuel sulfur ≤ 15ppm in June 2008 • PM aftertreatment-based standards introduced in 2009-10 • NOx aftertreatment-based standards introduced in 2011-12 *See Figure 12.1.1-3*
Option 1b	Same as Option 1a, except fuel sulfur standard required two years earlier *See Figure 12.1.1-4*

Figure 12.1.1-1
Existing Engine and Fuel Standards

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2: 5.6 NOx+NMHC, 0.6 PM										
25 ≤ hp hp < 50	Tier 2: 5.6 NOx+NMHC, 0.4 PM										
50 ≤ hp hp < 75	Tier 2: 5.6 NOx+NMHC 0.3 PM			Tier 3: 3.5 NOx+NMHC 0.3 PM							
75 ≤ hp hp < 100											
100 ≤ hp hp < 175	Tier 2: 4.9 NOx+NMHC 0.2 PM		Tier 3: 3.0 NOx+NMHC 0.2 PM								
175 ≤ hp hp < 750	Tier 2: 4.8 NOx+NMHC 0.1 PM	Tier 3: 3.0 NOx+NMHC 0.1 PM									
hp ≥ 750	Tier 1: 6.9 NOx 0.4 PM	Tier 2: 4.8 NOx+NMHC 0.1 PM									
Fuel sulfur standard (ppm)											
Loco & marine	Uncontrolled										
Nonroad	Uncontrolled										

[α] Applies to model years.

Figure 12.1.1-2
Engine and Fuel Standards Under Option 1



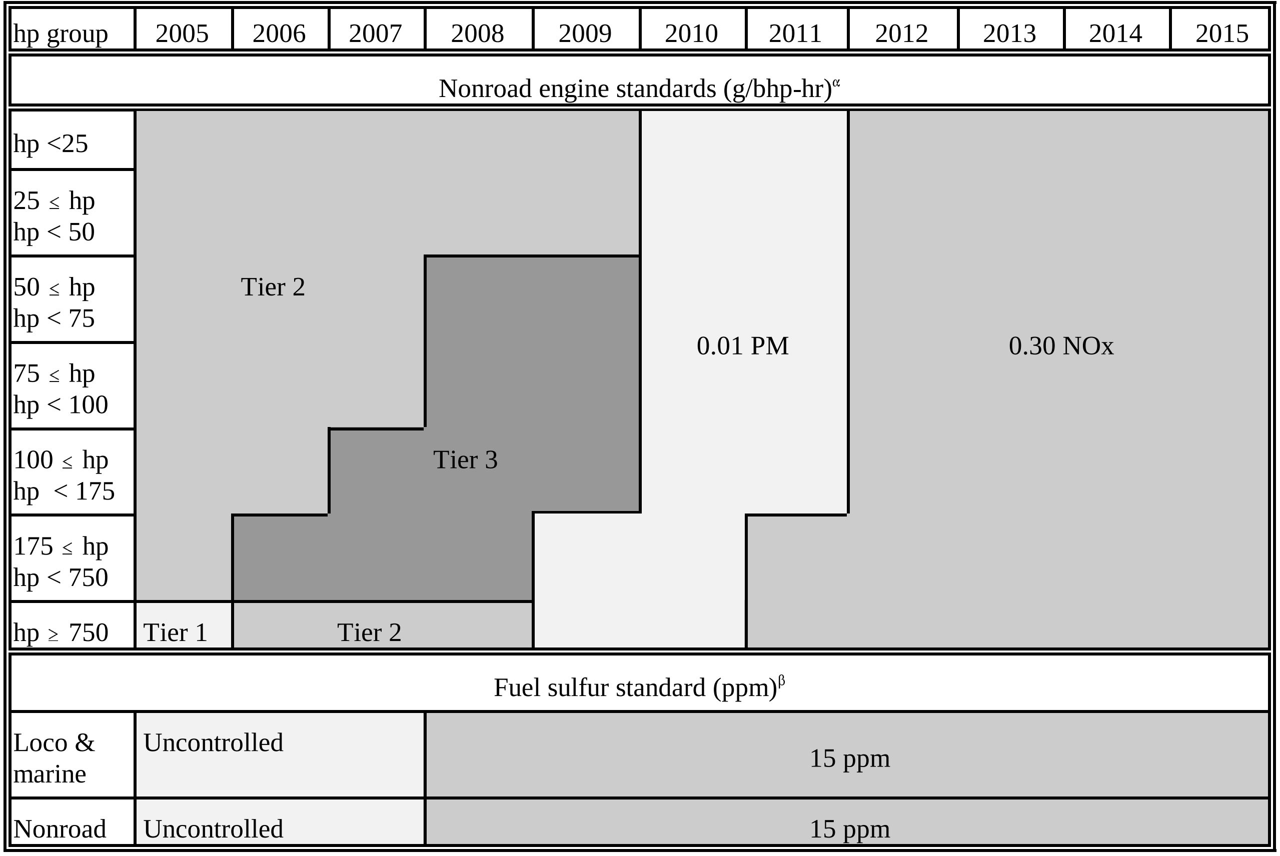
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50				0.22 PM					0.02 PM, 3.3[γ] NOx		
50 ≤ hp hp < 75				Tier 3							
75 ≤ hp hp < 100						50%: 0.01 PM		0.01 PM 50%: 0.30 NOx		0.30 NOx	
100 ≤ hp hp < 175											
175 ≤ hp hp < 750											
hp ≥ 750	Tier 1	Tier 2					50%: 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled			500 ppm							
Nonroad	Uncontrolled			15 ppm							

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[γ] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.1-3
Engine and Fuel Standards Under Option 1a



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2					0.01 PM		0.30 NOx			
25 ≤ hp hp < 50											
50 ≤ hp hp < 75				Tier 3							
75 ≤ hp hp < 100											
100 ≤ hp hp < 175											
175 ≤ hp hp < 750					0.01 PM		0.30 NOx				
hp ≥ 750	Tier 1	Tier 2									
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled			15 ppm							
Nonroad	Uncontrolled			15 ppm							

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

Figure 12.1.1-4
Engine and Fuel Standards Under Option 1b

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2	Tier 2	Tier 2	Tier 2	Tier 2	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
25 ≤ hp hp < 50	Tier 2	Tier 2	Tier 2	Tier 2	Tier 2	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
50 ≤ hp hp < 75	Tier 2	Tier 2	Tier 2	Tier 3	Tier 3	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
75 ≤ hp hp < 100	Tier 2	Tier 2	Tier 2	Tier 3	Tier 3	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
100 ≤ hp hp < 175	Tier 2	Tier 2	Tier 3	Tier 3	Tier 3	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
175 ≤ hp hp < 750	Tier 2	Tier 3	Tier 3	Tier 3	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
hp ≥ 750	Tier 1	Tier 2	Tier 2	Tier 2	0.01 PM	0.01 PM	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx	0.30 NOx
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm
Nonroad	Uncontrolled	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

12.1.2 Two-Step Options

Two-step options are those in which the fuel sulfur standard is set first at 500ppm for several years, and then is lowered further to 15ppm. The exact timing of the introduction of the 500ppm and the 15ppm standards varies among each of the two-step options. In addition, we considered a variety of engine standards and phase-ins. In the two-step options, the transient test cycle is required concurrently with the introduction of the transitional Tier 4 engine standards. The one exception is Option 5b, under which the existing steady-state test applies indefinitely for <75 hp engines.

Our proposed program forms the basis for all of the two-step program options. The two-step options are summarized in Table 12.1.2-1. Following this table is a summary of the existing Tier 1, Tier 2, and Tier 3 standards from 40 CFR §89.112 that form the baseline of our analyses. The specifics of the two-step options are shown in the standard charts in Figures 12.1.2-2 through 11.

As for the one-step standard charts, only changes to the standards are shown, i.e. if no new standard for a given pollutant is indicated, the previous standard applies.

Table 12.1.2-1
Summary of Two-Step Options

Option	Summary Description
Proposed program	• 500 ppm in 2007; 15 ppm in 2010 for nonroad engines only • >25 hp: PM aftertreatment-based standards introduced 2011-2013 • >75 hp: NOx aftertreatment-based standards introduced and phased-in 2011-2014 • <25 hp: PM standards in 2008 • 25-75 hp: PM standards in 2008 (optional for 50-75 hp) *See Figure 12.1.2-2*
Option 2a	Same as our proposed program, except: • Transitional sulfur standard of 500 ppm is introduced one year earlier *See Figure 12.1.2-3*
Option 2b	Same as our proposed program, except: • Final sulfur standard of 15 ppm is introduced one year earlier • Trap-based PM standards begin one year earlier for all engines *See Figure 12.1.2-4*
Option 2c	Same as our proposed program, except: • Final sulfur standard of 15 ppm is introduced one year earlier • Trap-based PM standards begin one year earlier for 175 - 750 hp engines *See Figure 12.1.2-5*
Option 2d	Same as our proposed program, except: • Final NOx standard for 25 - 75 hp engines is lowered to 0.30 g/bhp-hr • A phase-in for the NOx standard for this horsepower group is included *See Figure 12.1.2-6*
Option 2e	Same as our proposed program, except: • No new Tier 4 NOx standards. *See Figure 12.1.2-7*
Option 3	Same as our proposed program, except: • Above-ground mining equipment >750 hp remains at the Tier 2 standards *See Figure 12.1.2-8*
Option 4	Same as our proposed program, except: • 15 ppm final sulfur standard applies to fuel used by locomotives and marine engines in addition to all other nonroad engines *See Figure 12.1.2-9*
Option 5a	Same as our proposed program, except: • No new Tier 4 standards for <75 hp engines *See Figure 12.1.2-10*
Option 5b	Same as our proposed program, except: • No trap-based PM standards for <75 hp engines • No new Tier 4 NOx standards for <75 hp engines *See Figure 12.1.2-11*

Figure 12.1.2-1
Existing Engine and Fuel Standards

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2: 5.6 NOx+NMHC, 0.6 PM										
25 ≤ hp hp < 50	Tier 2: 5.6 NOx+NMHC, 0.4 PM										
50 ≤ hp hp < 75	Tier 2: 5.6 NOx+NMHC 0.3 PM			Tier 3: 3.5 NOx+NMHC 0.3 PM							
75 ≤ hp hp < 100											
100 ≤ hp hp < 175	Tier 2: 4.9 NOx+NMHC 0.2 PM		Tier 3: 3.0 NOx+NMHC 0.2 PM								
175 ≤ hp hp < 750	Tier 2: 4.8 NOx+NMHC 0.1 PM	Tier 3: 3.0 NOx+NMHC 0.1 PM									
hp ≥ 750	Tier 1: 6.9 NOx 0.4 PM	Tier 2: 4.8 NOx+NMHC 0.1 PM									
Fuel sulfur standard (ppm)											
Loco & marine	Uncontrolled										
Nonroad	Uncontrolled										

[α] Applies to model years.

Figure 12.1.2-2
Engine and Fuel Standards under the Proposed Program

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50				0.22 PM					0.02 PM, 3.3[ε] NOx		
50 ≤ hp hp < 75											
75 ≤ hp hp < 100				Tier 3				100%[γ] : 0.01 PM 50%[γ] : 0.30 NOx		0.01 PM 0.30 NOx	
100 ≤ hp hp < 175											
175 ≤ hp hp < 750											
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled		500 ppm								
Nonroad	Uncontrolled		500 ppm			15 ppm					

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

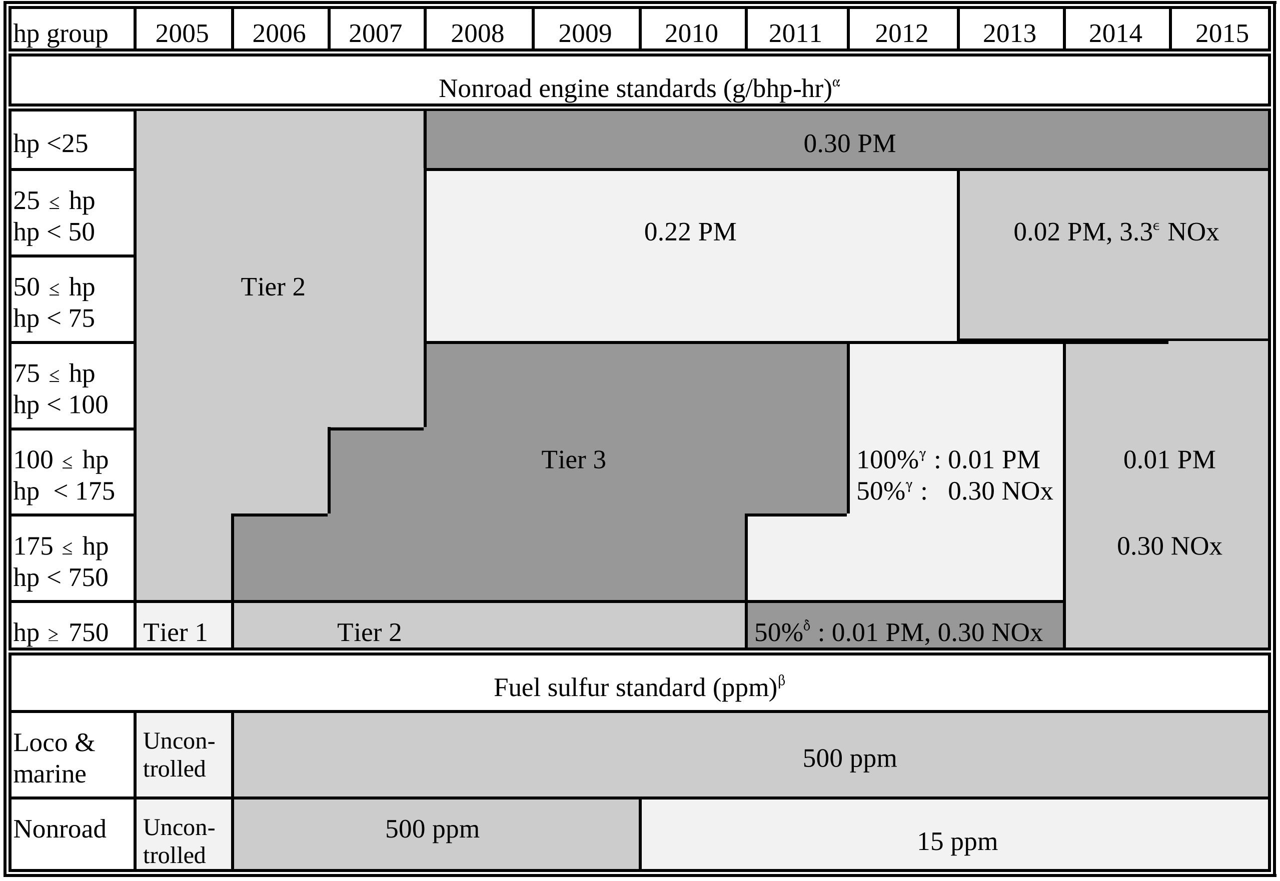
[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

[ε] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.2-3
Engine and Fuel Standards under Option 2a



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50				0.22 PM					0.02 PM, 3.3[ε] NOx		
50 ≤ hp hp < 75											
75 ≤ hp hp < 100				Tier 3				100%[γ] : 0.01 PM 50%[γ] : 0.30 NOx		0.01 PM 0.30 NOx	
100 ≤ hp hp < 175											
175 ≤ hp hp < 750											
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncon-trolled	500 ppm									
Nonroad	Uncon-trolled	500 ppm				15 ppm					

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

[ε] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.2-4
Engine and Fuel Standards under Option 2b

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50	Tier 2			0.22 PM				0.02 PM	0.02 PM, 3.3[ε] NOx		
50 ≤ hp hp < 75	Tier 2			0.22 PM				0.02 PM, 3.3[ε] NOx			
75 ≤ hp hp < 100	Tier 2			Tier 3			0.01 PM	50%[γ] : 0.30 NOx		0.01 PM 0.30 NOx	
100 ≤ hp hp < 175	Tier 2		Tier 3				0.01 PM	50%[γ] : 0.30 NOx		0.01 PM 0.30 NOx	
175 ≤ hp hp < 750	Tier 2	Tier 3				0.01 PM	50%[γ] : 0.30 NOx			0.01 PM 0.30 NOx	
hp ≥ 750	Tier 1	Tier 2				50%: 0.01 PM	50%[δ] : 0.01 PM, 0.30 NOx		100%: 0.01 PM	0.01 PM 0.30 NOx	
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled		500 ppm								
Nonroad	Uncontrolled		500 ppm		15 ppm						

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

[ε] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.2-5
Engine and Fuel Standards under Option 2c

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25				0.30 PM							
25 ≤ hp hp < 50				0.22 PM					0.02 PM, 3.3[ε] NOx		
50 ≤ hp hp < 75		Tier 2									
75 ≤ hp hp < 100											
100 ≤ hp hp < 175					Tier 3			100%[γ] : 0.01 PM 50%[γ] : 0.30 NOx		0.01 PM	
175 ≤ hp hp < 750						0.01 PM				0.30 NOx	
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled		500 ppm								
Nonroad	Uncontrolled		500 ppm		15 ppm						

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

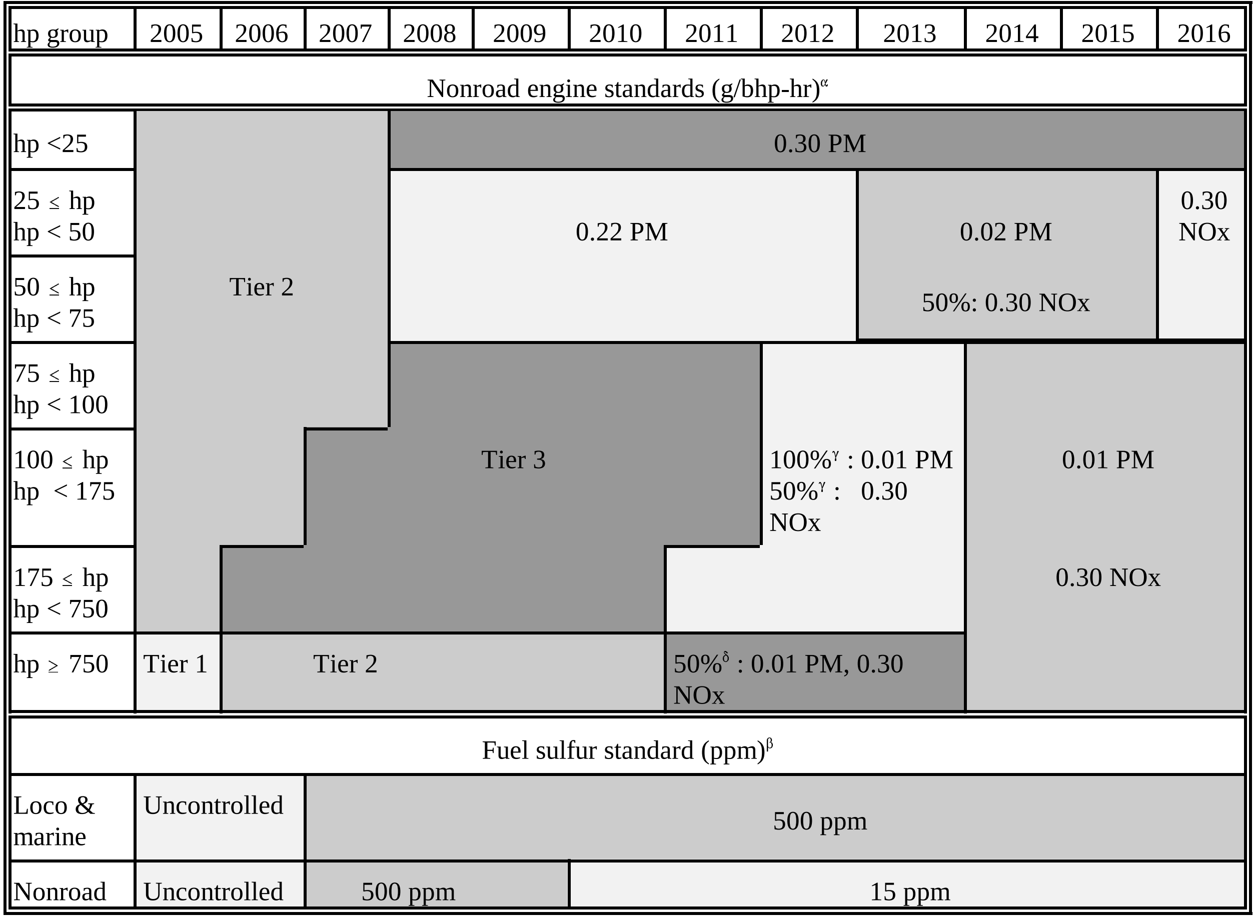
[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

[ε] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.2-6
Engine and Fuel Standards under Option 2d



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Nonroad engine standards (g/bhp-hr)[α]												
hp <25				0.30 PM								
25 ≤ hp hp < 50				0.22 PM					0.02 PM			0.30 NOx
50 ≤ hp hp < 75	Tier 2								50%: 0.30 NOx			
75 ≤ hp hp < 100												
100 ≤ hp hp < 175			Tier 3					100%[γ] : 0.01 PM 50%[γ] : 0.30 NOx		0.01 PM		
175 ≤ hp hp < 750										0.30 NOx		
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM, 0.30 NOx					
Fuel sulfur standard (ppm)[β]												
Loco & marine	Uncontrolled		500 ppm									
Nonroad	Uncontrolled		500 ppm			15 ppm						

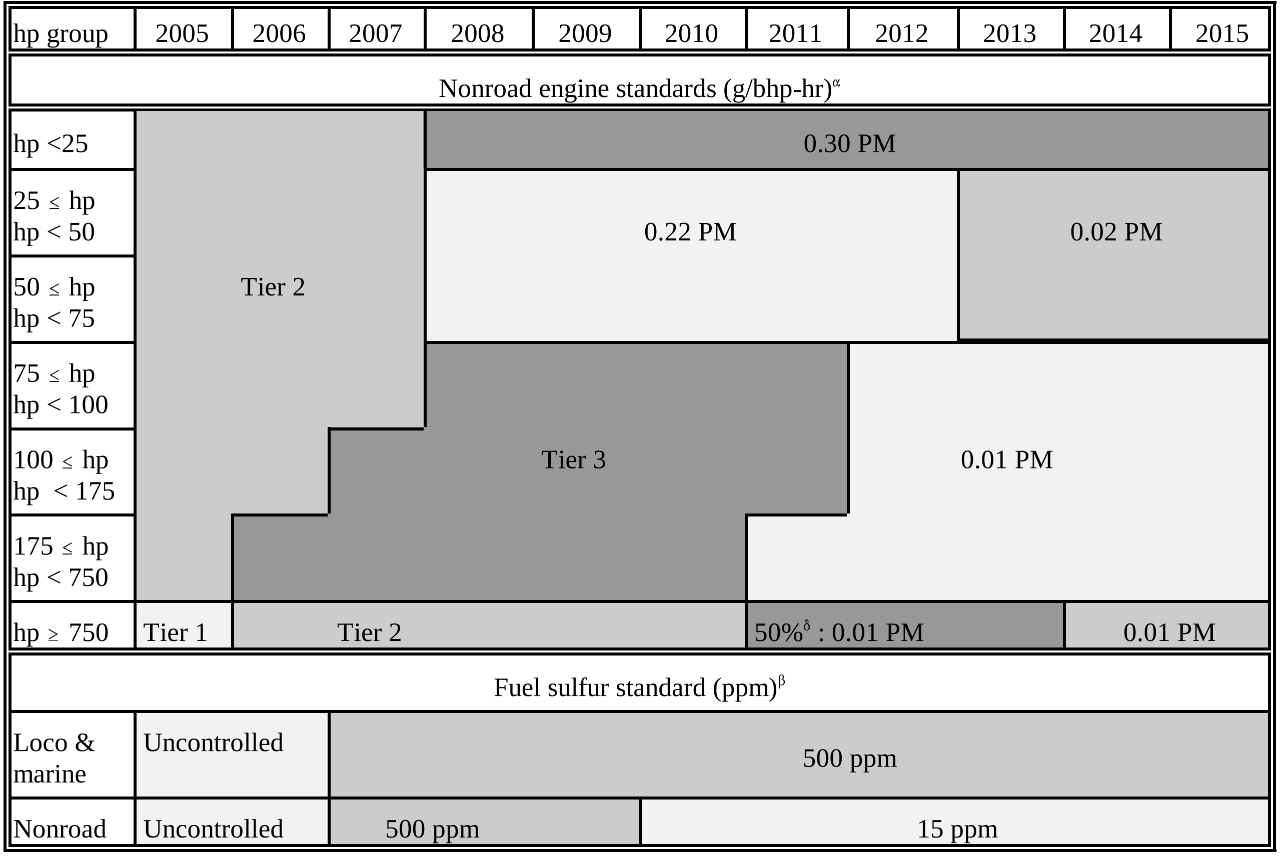
[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

Figure 12.1.2-7
Engine and Fuel Standards under Option 2e



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50				0.22 PM					0.02 PM		
50 ≤ hp hp < 75											
75 ≤ hp hp < 100				Tier 3				0.01 PM			
100 ≤ hp hp < 175											
175 ≤ hp hp < 750											
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM			0.01 PM	
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled		500 ppm								
Nonroad	Uncontrolled		500 ppm			15 ppm					

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[δ] Only 50% of engines must meet the new PM standard on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

Figure 12.1.2-8
Engine and Fuel Standards under Option 3

<table>
<tr><th>hp group</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th></tr>
<tr><td colspan="12">Nonroad engine standards (g/bhp-hr)[α]</td></tr>
<tr><td>hp <25</td><td colspan="3" rowspan="4">Tier 2</td><td colspan="8">0.30 PM</td></tr>
<tr><td>25 ≤ hp
hp < 50</td><td colspan="5" rowspan="2">0.22 PM</td><td colspan="3" rowspan="2">0.02 PM, 3.3[ε] NOx</td></tr>
<tr><td>50 ≤ hp
hp < 75</td></tr>
<tr><td>75 ≤ hp
hp < 100</td><td colspan="4">Tier 3</td><td colspan="2" rowspan="2">100%[γ] : 0.01 PM
50%[γ] : 0.30 NOx</td><td colspan="2" rowspan="3">0.01 PM
0.30 NOx</td></tr>
<tr><td>100 ≤ hp
hp < 175</td><td colspan="2"></td><td colspan="5"></td></tr>
<tr><td>175 ≤ hp
hp < 750</td><td></td><td colspan="5"></td><td colspan="3"></td></tr>
<tr><td>hp ≥ 750</td><td>Tier 1</td><td colspan="5">Tier 2</td><td colspan="3">50%[δ] : 0.01 PM, 0.30 NOx
Mining equipment remains at Tier 2</td><td colspan="2">0.01 PM
0.30 NOx
Mining equipment at Tier 2</td></tr>
<tr><td colspan="12">Fuel sulfur standard (ppm)[β]</td></tr>
<tr><td>Loco & marine</td><td colspan="2">Uncontrolled</td><td colspan="9">500 ppm</td></tr>
<tr><td>Nonroad</td><td colspan="2">Uncontrolled</td><td colspan="3">500 ppm</td><td colspan="6">15 ppm</td></tr>
</table>

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines not used in mining equipment must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

[ε] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.2-9
Engine and Fuel Standards under Option 4

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50				0.22 PM					0.02 PM, 3.3[ε] NOx		
50 ≤ hp hp < 75											
75 ≤ hp hp < 100				Tier 3				100%[γ] : 0.01 PM 50%[γ] : 0.30 NOx		0.01 PM 0.30 NOx	
100 ≤ hp hp < 175											
175 ≤ hp hp < 750											
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled		500 ppm			15 ppm					
Nonroad	Uncontrolled		500 ppm			15 ppm					

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

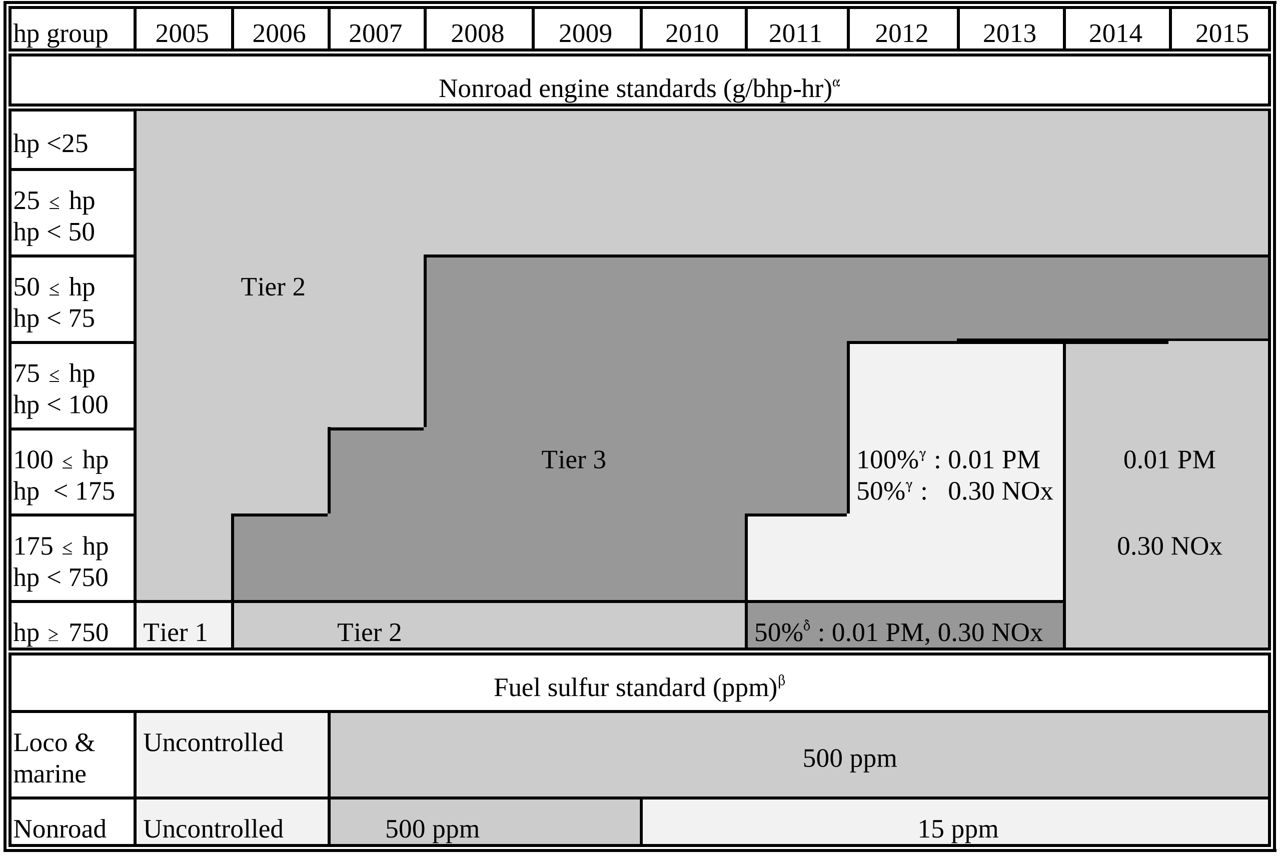
[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

[ε] Actual standard is 3.5g/bhp-hr NOx+NMHC, equivalent to the Tier 3 standard for 50-75hp. For modeling purposes, NOx portion of this standard is assumed to be 3.3g/bhp-hr.

Figure 12.1.2-10
Engine and Fuel Standards under Option 5a



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)$^{\alpha}$											
hp <25											
25 ≤ hp hp < 50											
50 ≤ hp hp < 75		Tier 2									
75 ≤ hp hp < 100											
100 ≤ hp hp < 175					Tier 3			100%$^{\gamma}$: 0.01 PM 50%$^{\gamma}$: 0.30 NOx		0.01 PM	
175 ≤ hp hp < 750										0.30 NOx	
hp ≥ 750	Tier 1	Tier 2					50%$^{\delta}$: 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)$^{\beta}$											
Loco & marine	Uncontrolled		500 ppm								
Nonroad	Uncontrolled		500 ppm			15 ppm					

$^{\alpha}$ Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

$^{\beta}$ Applies to calender years. Begins in June.

$^{\gamma}$ All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

$^{\delta}$ Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

Figure 12.1.2-11
Engine and Fuel Standards under Option 5b

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad engine standards (g/bhp-hr)[α]											
hp <25	Tier 2			0.30 PM							
25 ≤ hp hp < 50				0.22 PM							
50 ≤ hp hp < 75											
75 ≤ hp hp < 100				Tier 3				100%[γ] : 0.01 PM 50%[γ] : 0.30 NOx		0.01 PM 0.30 NOx	
100 ≤ hp hp < 175											
175 ≤ hp hp < 750											
hp ≥ 750	Tier 1	Tier 2					50%[δ] : 0.01 PM, 0.30 NOx				
Fuel sulfur standard (ppm)[β]											
Loco & marine	Uncontrolled		500 ppm								
Nonroad	Uncontrolled		500 ppm			15 ppm					

[α] Applies to model years. If no standard is shown for a given pollutant, the previous standard applies.

[β] Applies to calender years. Begins in June.

[γ] All engines must meet 0.01 PM, but only 50% of engines must meet the new NOx standard of 0.30. All engines must use the transient test cycle.

[δ] Only 50% of engines must meet both the new PM and NOx standards on the transient test cycle. Remaining engines meet Tier 2 standards on the steady-state test cycle.

12.2 Emission Inventory Impacts Comparison

This section presents the nonroad inventory impacts of all the program options just set forth that we considered during development of our proposed program. The methodology and assumptions used to generate the inventories for all program options are the same as those described in Chapter 3 for the baseline (no new Tier 4 standards) and our proposed program. The primary differences between the assumptions made for our proposed program versus those made for the other program options are related to in-use fuel and certification fuel sulfur levels. These differences are described in Section 12.2.1 below.

The inventories presented in this section represent all nonroad equipment categories, as well as locomotive and CI marine which are affected by the fuel standards, although not by the engine standards. We have not included any potential credits generated under ABT. The PM inventories include directly emitted sulfate PM (in the form of hydrated sulfuric acid) but do not include secondary sulfates produced from $_{SO2}$ in the atmosphere.

12.2.1 Assumptions Regarding Fuel Sulfur Content

Among the program options we considered, there are variations in the timing and level of the fuel sulfur standard. These variations impact both the in-use sulfur level and the certification sulfur level, which in turn affect the PM and $_{SO2}$ inventories estimated via the NONROAD model. This section presents our approach to in-use and certification fuel sulfur levels.

12.2.1.1 Certification Fuel

Fuel used to certify new nonroad engines should be representative of the fuel that those engines will use during their lifetime. Thus the specified maximum sulfur content of nonroad diesel certification fuel should change in concert with the in-use sulfur standard. For instance, our proposed program includes a 500ppm in-use sulfur standard that goes into effect in June of 2007, followed by a 15ppm sulfur standard that goes into effect in June of 2010. Nonroad engine manufacturers must therefore show that their engines can meet the standards when tested on fuel with a sulfur level as high as 500ppm during model years 2008 through 2010, and as high as 15ppm for model years 2011 and beyond.

For most program options, the certification fuel sulfur specification will change in the year following a change in the in-use fuel sulfur standard. However, we took a different approach for Options 1b and 2a. Both of these options are intended to show the impact that an earlier change from uncontrolled to controlled in-use sulfur levels will have on the PM inventories. In order to generate the full benefits of these options, our modeling does not include a concurrent change to certification fuel sulfur levels. In other words, we model an in-use reduction in sulfate PM and SO_2 emissions as a result of the in-use fuel having less sulfur than the certification fuel. If the certification fuel were set at a sulfur level equal to the in-use fuel sulfur level, there would be no in-use reduction in sulfate PM or SO_2 emissions.

A lower maximum sulfur specification for certification fuel makes it easier to comply with the PM standard, since, as shown in Chapter 4 of this draft RIA, lower fuel sulfur means less sulfate PM. Manufacturers could take advantage of this benefit of lower sulfur content in certification fuel by modifying their engines to reduce costs. However, if the change in certification fuel sulfur level does not exactly coincide with a change in the applicable engine emission standards, making modifications to an engine family simply to take advantage of the lower sulfur level of certification fuel may not be cost-effective. Therefore, we have made the assumption that engines within any horsepower group will only be modified to account for a lower certification fuel sulfur level when new engine standards become effective. In other words, for modeling purposes, all engines are assumed to be certified at the sulfur level that applied when the most recent set of emission standards became effective. This approach results in slightly larger in-use PM benefits, since there will be occasions when manufacturers are in effect meeting the PM standard using certification fuel with a higher-than-necessary sulfur level.

The assumed cert fuel sulfur levels were used to establish the proper zero-hour emission factors for new engines. For in-use inventory impacts of these new engines, the emission factors were further adjusted to account for the assumed in-use sulfur levels. Thus, for instance, engines certified on 2000ppm sulfur fuel and then operated on 500ppm fuel would realize a PM benefit relative to the PM certification standard.

The sulfur levels assumed for certification fuel for the purposes of establishing the zero-hour emission factors are given in Appendix 12A.

12.2.1.2 In-Use Fuel

Section 12.1 presented the sulfur standards that would apply to in-use nonroad fuel under each of the program options we evaluated. In order to calculate emission inventories using the NONROAD model, we estimated the likely in-use average sulfur level by calendar year for each of the options. These average sulfur values were a function of the level and timing of transitional and final standards, expected refiner compliance margins, and the amount of highway diesel fuel which is consumed by nonroad engines (so-called "spillover"). The various factors used in the calculations are listed in Table 12.2.1.2-1, based on the derivations and discussion presented in Section 7.1.4.2.

Table 12.2.1.2-1
Factors Used to Calculate In-use Sulfur Levels

Average in-use fuel sulfur level for any fuel designed to meet a standard of 500 ppm	340 ppm
Average in-use fuel sulfur level for fuel designed to meet California's diesel fuel specifications	120 ppm
Average in-use fuel sulfur level for any fuel designed to meet a standard of 15 ppm	11 ppm
Average in-use sulfur level for fuel intended to be used in nonroad engines, prior to sulfur control	3400 ppm
Nonroad spillover: Fraction of fuel consumed by nonroad engines which is actually designed to meet on-highway fuel sulfur standards	34.9%
Locomotive/marine spillover: Fraction of fuel consumed by locomotives and marine engines which is actually designed to meet on-highway fuel sulfur standards	32.4%

We first determined the average in-use sulfur level for highway fuel by calender year, using the factors in Table 12.2.1.2-1 and the phase-in schedule adopted in 2001 (66 FR 5002, January 18, 2001). Table 12.2.1.2-2 presents these sulfur levels.

Table 12.2.1.2-2
Average Sulfur Level for On-highway Fuel

Year	Average sulfur (ppm)	Explanation
≤ 2005	300	Nationwide average, including California, prior to introduction of 15ppm standard. Assumes 10% of nationwide highway diesel meets California's requirements.
2006	165	15ppm standard applies beginning in June. Only 80% of the pool meets the 15ppm standard.
2007	69	Only 80% of the pool meets the 15ppm standard.
2008	69	Only 80% of the pool meets the 15ppm standard.
2009	69	Only 80% of the pool meets the 15ppm standard.
≥ 2010	11	100% of the pool meets the 15ppm standard

We then determined the average in-use sulfur level for off-highway fuel. All of the program options we evaluated include one or more of the following types of transitions, for either nonroad fuel or locomotive and marine fuel:

- Transition from uncontrolled sulfur levels to a 500ppm standard
- Transition from a 500ppm sulfur standard to a 15ppm standard
- Transition from uncontrolled sulfur levels to a 15ppm standard

Every one of these transitions is assumed to occur in June, regardless of the calendar year in which the new standard applies. Using the average sulfur levels presented in Table 12.2.1.2-1, we generated in-use average sulfur levels for off-highway diesel fuel for the three types of transitions shown above. Table 12.2.1.2-3 presents the results.

Table 12.2.1.2-3
Average Sulfur Levels for Off-highway Fuel Sulfur Standard Transitions (ppm)

	Uncontrolled to 500ppm standard	500ppm standard to 15ppm standard	Uncontrolled to 15ppm standard
Prior to transition year	3400	340	3400
Transition year	1615	148	1423
After transition year	340	11	11

Finally, to calculate the in-use average sulfur levels under the various program options we evaluated, we combined the average sulfur levels for on-highway fuel from Table 12.2.1.2-2 with the average sulfur levels for off-highway fuel from Table 12.2.1.2-3. The spillover fractions given in Table 12.2.1.2-1 were used to properly weight the on-highway and off-highway average sulfur levels. The results for all program options are given in Tables 12.2.1.2-4 and 12.2.1.2-5, based on the fuel sulfur standards associated with each option as described in Section 12.1.

Table 12.2.1.2-4
In-use Average Sulfur Levels Used for Modeling Nonroad Engines (ppm)

	≤2005	2006	2007	2008	2009	2010	≥2011
Baseline	2318	2271	2237	2237	2237	2217	2217
Proposed program	2318	2271	1075	245	245	100	11
Option 1	2318	2271	2237	950	31	11	11
Option 1a	2318	2271	2237	950	31	11	11
Option 1b	2318	984	31	31	31	11	11
Option 2a	2318	1109	245	245	245	100	11
Option 2b	2318	2271	1075	245	120	11	11
Option 2c	2318	2271	1075	245	120	11	11
Option 2d	2318	2271	1075	245	245	100	11
Option 2e	2318	2271	1075	245	245	100	11
Option 3	2318	2271	1075	245	245	100	11
Option 4	2318	2271	1075	245	245	100	11
Option 5a	2318	2271	1075	245	245	100	11
Option 5b	2318	2271	1075	245	245	100	11

Table 12.2.1.2-5
In-use Average Sulfur Levels Used for Modeling Locomotive and Marine Engines (ppm)

	≤2005	2006	2007	2008	2009	2010	≥2011
Baseline	2396	2352	2321	2321	2321	2302	2302
Proposed program	2396	2352	1114	252	252	233	233
Option 1	2396	2352	2321	1114	252	233	233
Option 1a	2396	2352	2321	984	30	11	11
Option 1b	2396	1016	30	30	30	11	11
Option 2a	2396	1145	252	252	252	233	233
Option 2b	2396	2352	1114	252	252	233	233
Option 2c	2396	2352	1114	252	252	233	233
Option 2d	2396	2352	1114	252	252	233	233
Option 2e	2396	2352	1114	252	252	233	233
Option 3	2396	2352	1114	252	252	233	233
Option 4	2396	2352	1114	252	252	104	11
Option 5a	2396	2352	1114	252	252	233	233
Option 5b	2396	2352	1114	252	252	233	233

12.2.2 Emission Inventories for Alternative Program Options

This section presents the absolute inventories associated with our proposed program and each of the program options we evaluated, in short tons per year. All inventories represent only those off-highway engines affected by our proposed program or each of the alternative program options - no on-highway, biogenic, or other sources are included. We have presented graphical illustrations separately for nonroad and locomotive/marine, since we are proposing engine standards only for the former, and have investigated fuel sulfur standards for locomotives and marine engines as a way to generate additional PM and SO_2 reductions. In addition, there are no changes to NOx, NMHC, or CO for locomotive and marine under any Option, so we have not shown separate graphs for these pollutants. Inventory tables include nonroad, locomotive, and marine sources for PM and SO_2, and just nonroad sources for NOx, CO, and NMHC.

Graphic representations of inventories are shown for all years through 2030, and tabulated values are provided for selected years. All values are presented as 50-state annual tons, and the particulate matter values are PM10. Note that the emission reductions used for the calculation of health and welfare benefits were based on 48-state inventories and the relevant particulate matter was PM2.5 due to the fact that the air quality modeling on which these benefits were based requires the use of these alternative measures of inventory impacts.

12.2.2.1 NOx

This section presents the NOx inventories for nonroad engines affected by our proposed program and the alternative program options. In general, the options represent little or no change in the NOx standard levels and timing in comparison with our proposed program. Primary differences are exhibited for:

- Options 1a and 1b for which NOx aftertreatment is required for all engines
- Option 2d which adds NOx aftertreatment-based standards for 25-75hp
- Option 2e which assumes no new Tier 4 NOx standards
- Option 3 which exempts large above-ground mining equipment

Figure 12.2.2.1-1
50-State Inventories for nonroad NOx (tons)

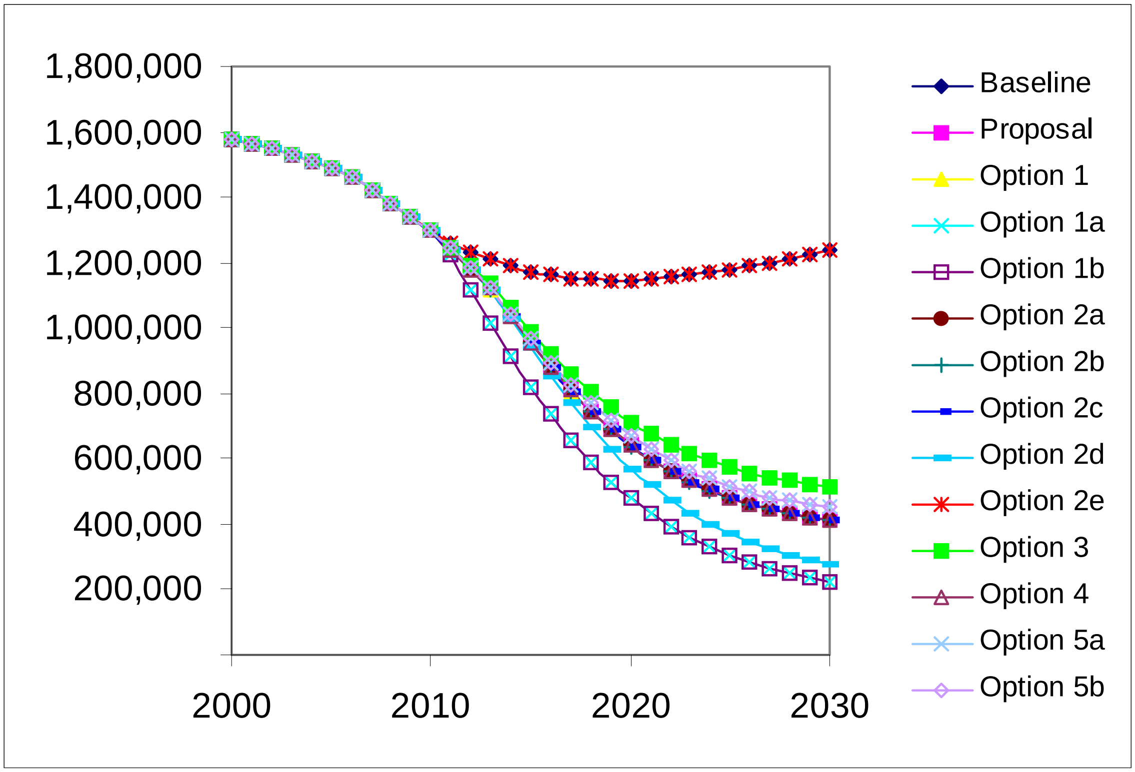


Table 12.2.2.1-1
50-State Inventories for NOx (tons)

	2010	2015	2020	2025	2030
Baseline	1,327,000	1,205,000	1,182,000	1,218,000	1,280,000
Proposed program	1,326,000	987,000	675,000	520,000	454,000
Option 1	1,325,000	986,000	675,000	520,000	454,000
Option 1a	1,327,000	853,000	514,000	343,000	265,000
Option 1b	1,327,000	853,000	514,000	343,000	265,000
Option 2a	1,326,000	987,000	675,000	520,000	454,000
Option 2b	1,325,000	984,000	674,000	519,000	453,000
Option 2c	1,324,000	985,000	674,000	519,000	453,000
Option 2d	1,326,000	974,000	605,000	411,000	320,000
Option 2e	1,327,000	1,205,000	1,182,000	1,218,000	1,280,000
Option 3	1,326,000	1,020,000	747,000	612,000	557,000
Option 4	1,326,000	987,000	675,000	520,000	454,000
Option 5a	1,327,000	1,000,000	703,000	555,000	495,000
Option 5b	1,327,000	1,000,000	703,000	555,000	495,000

12.2.2.2 PM

Particulate matter directly affected by our proposed program is included in these inventories. Although the majority of diesel exhaust PM is fine (<2.5 microns), we have included all PM up to 10 microns in our inventory estimates to most properly account for the full impacts of our proposed program. In terms of PM inventory impacts, differences between each of the alternative program options and our proposed program are exhibited for most of the program options.

Figure 12.2.2.2-1
50-State Inventories for nonroad PM (tons)

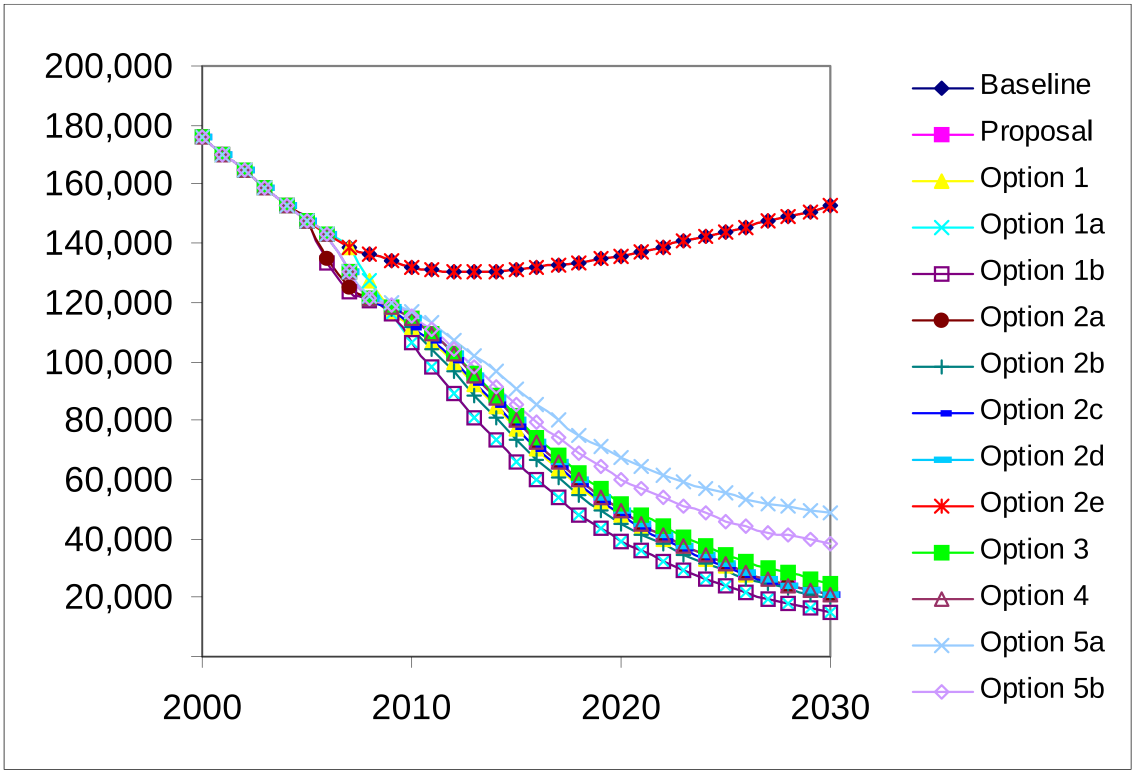


Figure 12.2.2.2-2
50-State Inventories for loco/marine PM (tons)

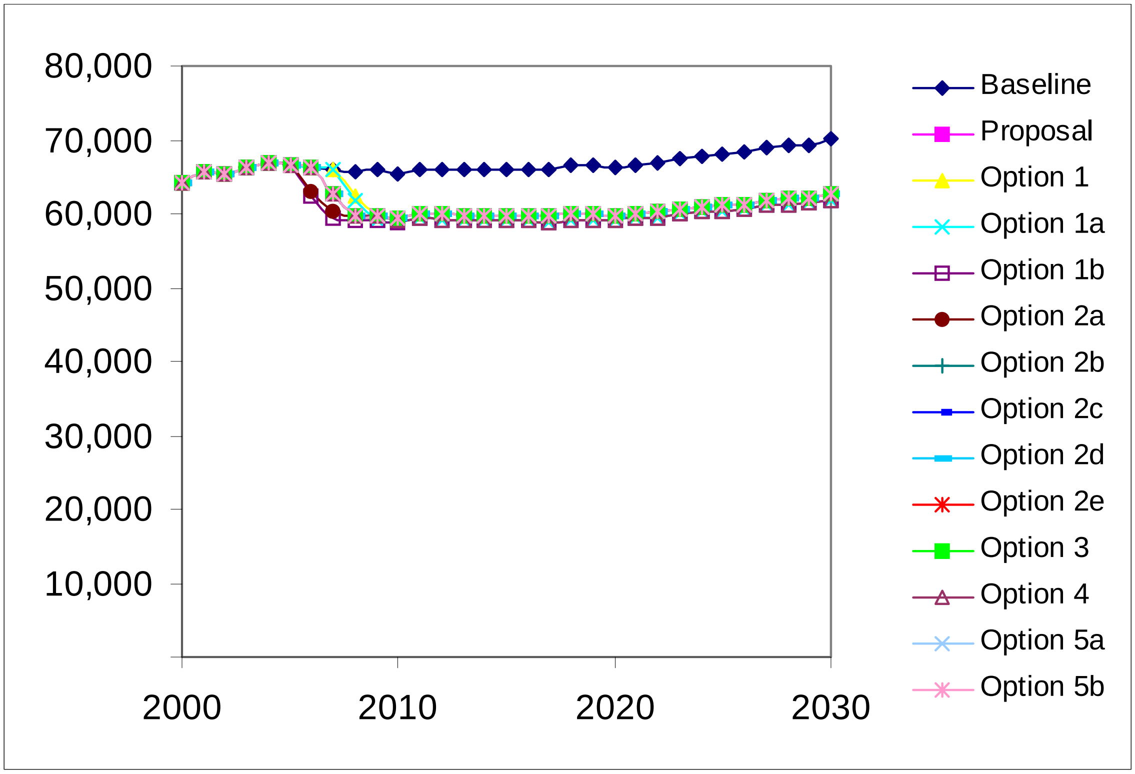


Table 12.2.2.2-1
50-State Inventories for total PM (tons)

	2010	2015	2020	2025	2030
Baseline	198,000	197,000	202,000	212,000	223,000
Proposed program	174,000	140,000	109,000	92,000	84,000
Option 1	171,000	137,000	108,000	92,000	83,000
Option 1a	165,000	125,000	98,000	84,000	77,000
Option 1b	165,000	125,000	98,000	84,000	77,000
Option 2a	174,000	140,000	109,000	92,000	84,000
Option 2b	171,000	133,000	105,000	90,000	83,000
Option 2c	171,000	137,000	108,000	92,000	83,000
Option 2d	174,000	140,000	109,000	92,000	84,000
Option 2e	174,000	140,000	109,000	92,000	84,000
Option 3	174,000	141,000	112,000	96,000	88,000
Option 4	173,000	139,000	108,000	92,000	83,000
Option 5a	177,000	150,000	127,000	116,000	111,000
Option 5b	175,000	145,000	120,000	107,000	101,000

12.2.2.3 NMHC

The new Tier 4 standards realize a significant reduction in NMHC emissions, including toxic hydrocarbons, due to the use of technologies such as oxidation catalysts and catalyzed diesel particulate filters. NMHC impacts exhibited by each alternative program option will largely mimic the PM impacts.

The NONROAD model provides total hydrocarbon emissions for both exhaust and crankcase emissions, though crankcase HC is typically only 1-2% of total HC. Methane and ethane are also included in total hydrocarbon output from NONROAD. However, our standards apply to non-methane hydrocarbons. Thus we have decided to convert total hydrocarbons from the NONROAD model into NMHC. To do this, total hydrocarbons is multiplied by 0.984[1], which subtracts out methane. Note that our air quality modeling requires volatile organic compounds (VOC) instead of total hydrocarbons, and many of the inventories with which we have compared the impacts of our proposed and alternative Tier 4 nonroad programs use VOCs. For these purposes, we converted total hydrocarbons from the NONROAD model into VOC by multiplying by 1.053, which subtracts out methane and ethane and simultaneously adds aldehydes.

Figure 12.2.2.3-1
50-State Inventories for nonroad NMHC (tons)

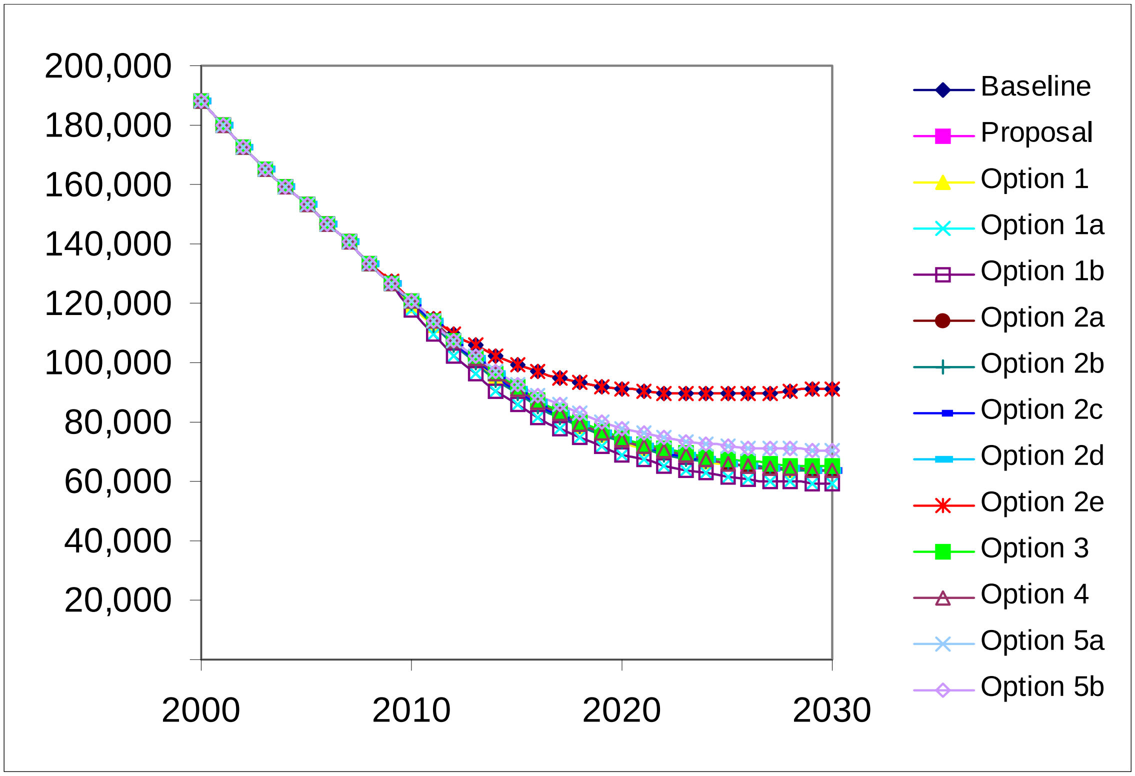


Table 12.2.2.3-1
50-State Inventories for NMHC (tons)

	2010	2015	2020	2025	2030
Baseline	122,000	100,000	92,000	91,000	93,000
Proposed program	122,000	92,000	75,000	68,000	65,000
Option 1	121,000	91,000	75,000	67,000	65,000
Option 1a	119,000	87,000	70,000	63,000	61,000
Option 1b	119,000	87,000	70,000	63,000	61,000
Option 2a	122,000	92,000	75,000	68,000	65,000
Option 2b	121,000	90,000	74,000	67,000	65,000
Option 2c	121,000	92,000	75,000	67,000	65,000
Option 2d	122,000	92,000	75,000	68,000	65,000
Option 2e	122,000	92,000	75,000	68,000	65,000
Option 3	122,000	93,000	76,000	69,000	66,000
Option 4	122,000	92,000	75,000	68,000	65,000
Option 5a	122,000	94,000	79,000	73,000	72,000
Option 5b	122,000	94,000	79,000	73,000	72,000

12.2.2.4 CO

The new Tier 4 standards realize a significant reduction in CO emissions due to the use of technologies such as oxidation catalysts and catalyzed diesel particulate filters. The minor adjustment we are proposing for CO standards is more of a bookeeping correction, as explained in the preamble. CO emissions are assumed to be reduced 90% for engines having a PM trap. Thus the CO impacts exhibited by each alternative program option will largely mimic the PM impacts.

Figure 12.2.2.4-1
50-State Inventories for nonroad CO (tons)

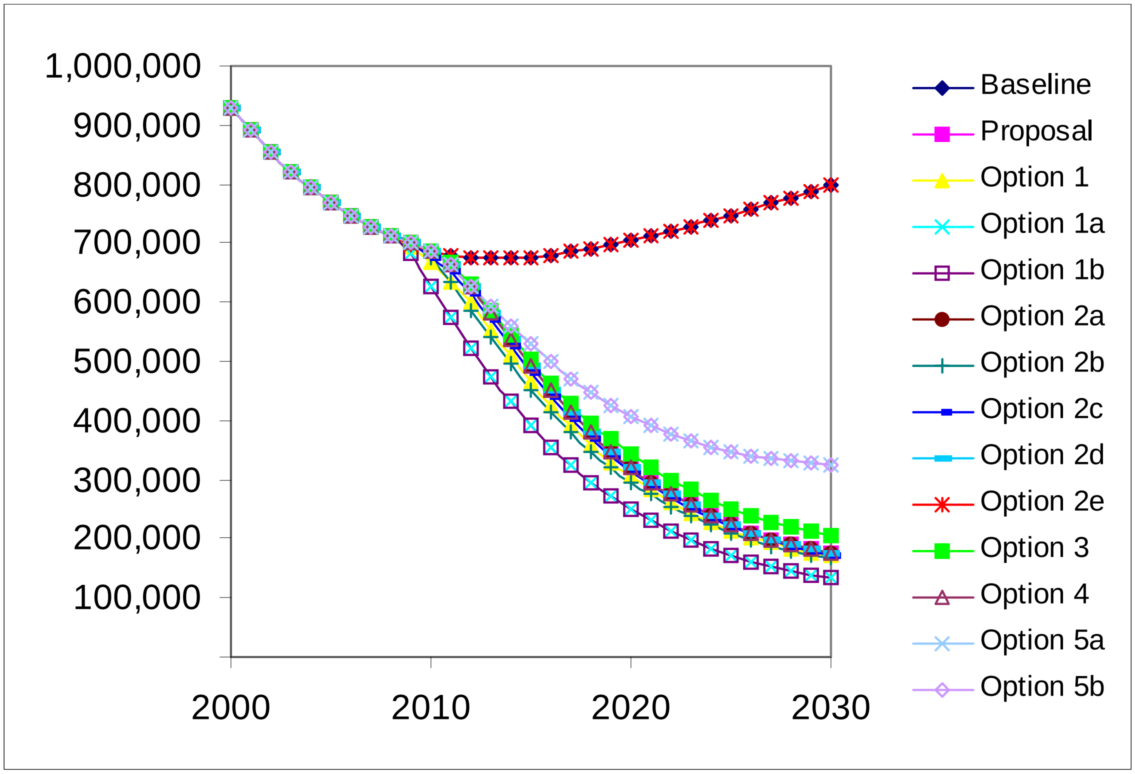


Table 12.2.2.4-1
50-State Inventories for CO (tons)

	2010	2015	2020	2025	2030
Baseline	693,000	682,000	709,000	754,000	805,000
Proposed program	693,000	498,000	326,000	230,000	181,000
Option 1	672,000	472,000	310,000	220,000	177,000
Option 1a	632,000	397,000	254,000	176,000	141,000
Option 1b	632,000	397,000	254,000	176,000	141,000
Option 2a	693,000	498,000	326,000	230,000	181,000
Option 2b	678,000	457,000	301,000	215,000	174,000
Option 2c	680,000	485,000	318,000	226,000	179,000
Option 2d	693,000	498,000	326,000	230,000	181,000
Option 2e	693,000	498,000	326,000	230,000	181,000
Option 3	693,000	508,000	348,000	258,000	212,000
Option 4	693,000	498,000	326,000	230,000	181,000
Option 5a	693,000	533,000	413,000	353,000	332,000
Option 5b	693,000	533,000	413,000	353,000	332,000

12.2.2.5 SO_2

Generally SO_2 emissions are proportional to fuel sulfur content. Thus differences in SO_2 inventories between our proposed program and the alternative program options are primarily a function of the differences in the assumed fuel programs. However, the assumed engine programs do play a small role, as the sulfur-to-SO_2 conversion rate decreases when aftertreatment-based standards are introduced, from a current conversion rate of approximately 98% to an ultimate conversion rate closer to 70%. Despite this engine-based impact of our proposed program on SO_2 emissions, we believe it is appropriate to associate all reductions in SO_2 with the costs of fuel sulfur reductions, as described in Chapter 8, since the 99% reduction in in-use nonroad fuel sulfur levels overwhelms any impact caused by changes in the sulfur-to-SO_2 conversion rate.

Figure 12.2.2.5-1
50-State Inventories for nonroad SO_2 (tons)

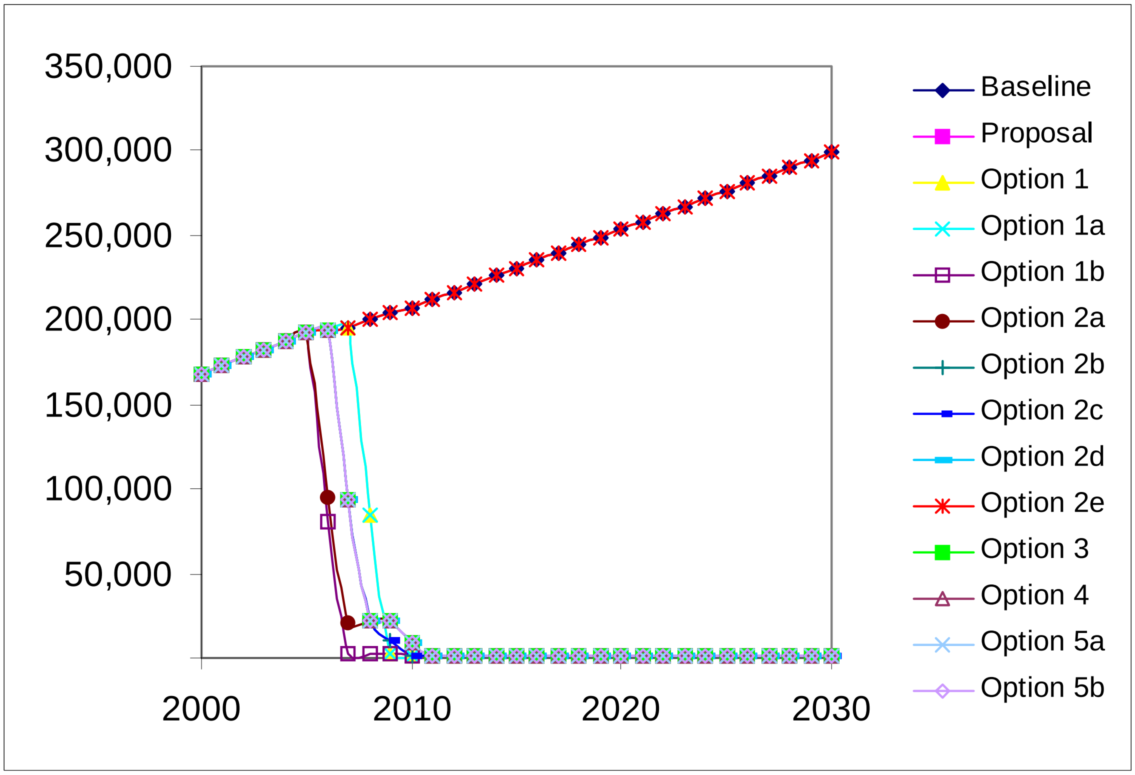


Figure 12.2.2.5-2
50-State Inventories for loco/marine SO_2 (tons)

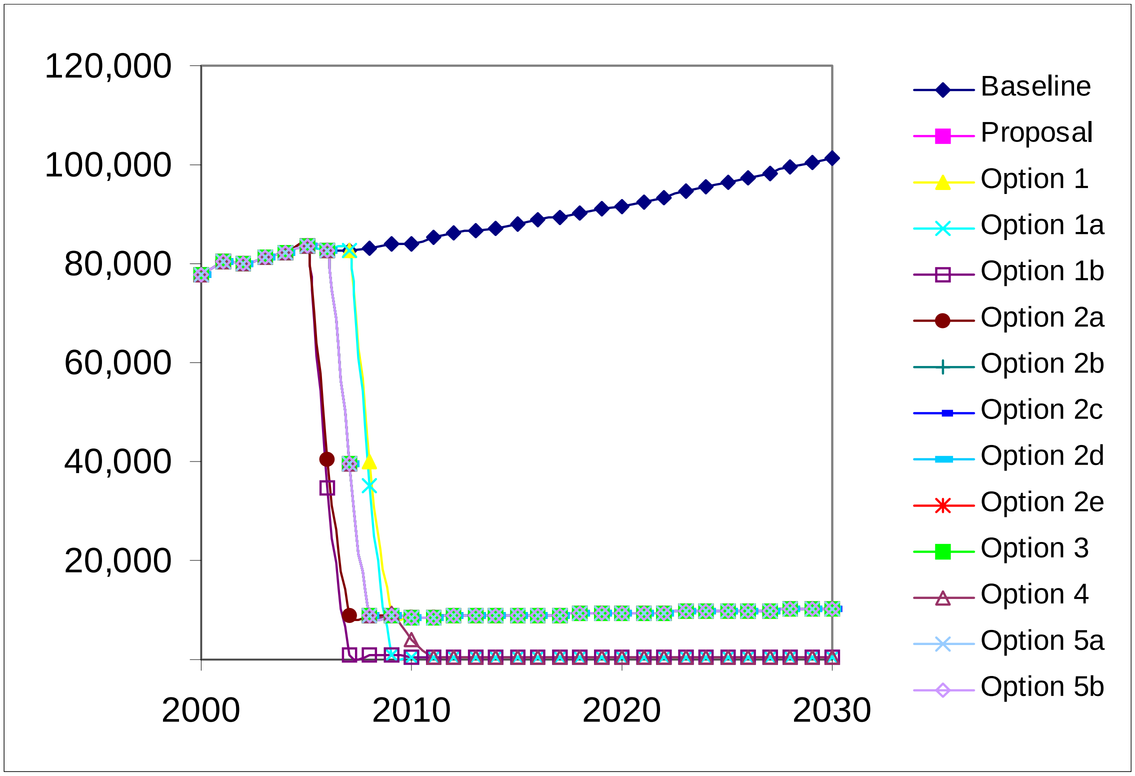


Table 12.2.2.5-1
50-State Inventories for total SO_2 (tons)

	2010	2015	2020	2025	2030
Baseline	291,000	318,000	345,000	373,000	401,000
Proposed program	18,000	10,000	10,000	11,000	11,000
Option 1	10,000	10,000	10,000	11,000	11,000
Option 1a	1,000	1,000	1,000	1,000	2,000
Option 1b	1,000	1,000	1,000	1,000	2,000
Option 2a	18,000	10,000	10,000	11,000	11,000
Option 2b	10,000	10,000	10,000	11,000	11,000
Option 2c	10,000	10,000	10,000	11,000	11,000
Option 2d	18,000	10,000	10,000	11,000	11,000
Option 2e	18,000	10,000	10,000	11,000	11,000
Option 3	18,000	10,000	10,000	11,000	11,000
Option 4	13,000	1,000	1,000	2,000	2,000
Option 5a	18,000	10,000	10,000	11,000	11,000
Option 5b	18,000	10,000	10,000	11,000	11,000

12.2.3 Cumulative Emission Reductions for Alternative Program Options

Inventory impacts of our proposed program and the alternative program options can be compared for individual calendar years or cumulatively over some timeframe. For the cumulative comparison, we have chosen to calculate the net present value of the annual emission reductions of each program, in comparison to the baseline, for all years through 2030. For this calculation we used a 3% discount rate to bring all tons into 2004. These net present value reductions are shown in Table 12.2.3-1. We also present the net present value of the differences between the emissions through 2030 for each alternative program option and our proposed program in Table 12.2.3-2.

Table 12.2.3-1
50-State Net Present Value Emission Reductions
In Comparison to Existing Standards Through 2030 (tons)

	NOx	PM	NMHC	CO	SO_2
Proposed program	5,407,000	1,126,000	184,000	4,149,000	4,952,000
Option 1	5,409,000	1,133,000	194,000	4,396,000	4,761,000
Option 1a	7,187,000	1,255,000	248,000	5,164,000	4,890,000
Option 1b	7,187,000	1,296,000	248,000	5,164,000	5,395,000
Option 2a	5,407,000	1,145,000	184,000	4,149,000	5,180,000
Option 2b	5,428,000	1,180,000	199,000	4,493,000	4,969,000
Option 2c	5,419,000	1,147,000	189,000	4,262,000	4,969,000
Option 2d	6,159,000	1,126,000	184,000	4,149,000	4,952,000
Option 2e	0	1,126,000	184,000	4,149,000	4,952,000
Option 3	4,665,000	1,097,000	175,000	3,924,000	4,952,000
Option 4	5,407,000	1,135,000	184,000	4,149,000	5,067,000
Option 5a	5,118,000	917,000	141,000	3,216,000	4,952,000
Option 5b	5,118,000	1,005,000	141,000	3,216,000	4,952,000

Table 12.2.3-2
50-State Net Present Value Emission Differences With Respect
To The Proposed Program, Through 2030 (tons)*

	NOx	PM	NMHC	CO	SO_2
Option 1	1,000	6,000	10,000	248,000	-191,000
Option 1a	1,780,000	129,000	63,000	1,015,000	-63,000
Option 1b	1,780,000	170,000	63,000	1,015,000	443,000
Option 2a	0	18,000	0	0	228,000
Option 2b	21,000	54,000	15,000	344,000	17,000
Option 2c	11,000	20,000	5,000	113,000	17,000
Option 2d	751,000	0	0	0	0
Option 2e	-5,407,000	0	0	0	0
Option 3	-742,000	-30,000	-9,000	-225,000	0
Option 4	0	9,000	0	0	114,000
Option 5a	-290,000	-209,000	-44,000	-933,000	0
Option 5b	-290,000	-121,000	-43,000	-933,000	0

*Positive values indicate that the Option produces greater environmental benefits, i.e. the Option results in a smaller cumulative absolute inventory

12.3 Benefits Comparison

We are able to estimate the benefits of various options using the benefit-transfer methodology developed in Chapter 9 for estimating the monetized benefits of the proposal. The specific methodology is described in Section 9.5 “Development of Intertemporal Scaling Factors and Calculation of Benefits Over Time” and will not be repeated here.

To use that methodology requires input of 48 state emission reductions for NOx, PM2.5 and SO_2 associated with each option. We cannot estimate 50 state benefits due to the fact that our air quality modeling work covers only 48 states, and we are unable to extrapolate those results to Alaska or Hawaii. PM2.5 is used for these calculations rather than PM10 because the underlying health effect studies rely on PM2.5 data.

The estimated 48 state emission reductions are given in Table 12.3-1, 12.3-2 and 12.3-3. Table 12.3-4 and Figure 12.3-1 present the estimated benefits for each of the options.

A key question for each of the options is how the benefits of that option compare with the benefits of our proposed program. Table 12.3-5 lists the difference in benefits between each of the options and the proposal. These differences are shown graphically in Figure 12.3-2.

Table 12.3-1A
48 State SO2 Emission Reductions for Program Options 1 - 2

Year	**Option 1**	**Option 1a**	**Option 1b**	**Option 2a**	**Option 2b**	**Option 2c**	**Option 2d**	**Option 2e**
2000	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0
2006	0	0	159,106	140,081	0	0	0	0
2007	0	0	271,364	245,048	142,948	142,948	142,948	142,948
2008	156,782	161,358	276,554	249,746	249,746	249,746	249,746	249,746
2009	273,998	281,907	281,907	254,544	265,904	265,860	254,543	254,543
2010	279,259	287,243	287,243	270,977	279,264	279,232	270,977	270,977
2011	285,014	293,130	293,130	285,003	285,025	285,014	285,003	285,003
2012	290,208	298,392	298,392	290,196	290,223	290,208	290,196	290,196
2013	295,325	303,562	303,562	295,312	295,340	295,323	295,312	295,312
2014	300,447	308,736	308,736	300,434	300,461	300,445	300,434	300,434
2015	305,653	314,001	314,001	305,639	305,665	305,650	305,639	305,639
2016	311,085	319,522	319,522	311,073	311,097	311,083	311,073	311,073
2017	316,310	324,813	324,813	316,299	316,319	316,307	316,299	316,299
2018	321,511	330,079	330,079	321,501	321,519	321,508	321,501	321,501
2019	326,735	335,371	335,371	326,725	326,741	326,732	326,725	326,725
2020	331,851	340,543	340,543	331,840	331,854	331,846	331,840	331,840
2021	337,241	346,020	346,020	337,231	337,243	337,236	337,231	337,231
2022	342,638	351,505	351,505	342,628	342,639	342,633	342,628	342,628
2023	348,041	356,998	356,998	348,032	348,042	348,037	348,032	348,032
2024	353,452	362,500	362,500	353,444	353,452	353,447	353,444	353,444
2025	358,871	368,010	368,010	358,863	358,870	358,866	358,863	358,863
2026	364,268	373,499	373,499	364,260	364,266	364,262	364,260	364,260
2027	369,673	378,998	378,998	369,665	369,670	369,667	369,665	369,665
2028	375,086	384,506	384,506	375,078	375,082	375,080	375,078	375,078
2029	380,509	390,025	390,025	380,500	380,504	380,502	380,500	380,500
2030	385,941	395,555	395,555	385,932	385,935	385,934	385,932	385,932

Table 12.3-1B
48 State SO2 Emission Reductions for Program Options 3 - 5

Year	Option 3	Option 4	Option 5a	Option 5b
2000	0	0	0	0
2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	142,948	142,948	142,948	142,948
2008	249,746	249,734	249,746	249,746
2009	254,543	254,532	254,544	254,544
2010	270,977	275,593	270,977	270,977
2011	285,001	293,072	285,003	285,003
2012	290,193	298,327	290,196	290,196
2013	295,308	303,496	295,307	295,307
2014	300,427	308,673	300,424	300,424
2015	305,630	313,942	305,624	305,624
2016	311,061	319,467	311,053	311,053
2017	316,284	324,764	316,274	316,274
2018	321,484	330,034	321,472	321,472
2019	326,706	335,330	326,693	326,693
2020	331,820	340,506	331,804	331,804
2021	337,209	345,986	337,192	337,192
2022	342,605	351,474	342,587	342,587
2023	348,008	356,969	347,988	347,988
2024	353,418	362,473	353,397	353,397
2025	358,837	367,985	358,814	358,814
2026	364,233	373,477	364,209	364,209
2027	369,637	378,977	369,612	369,612
2028	375,050	384,487	375,023	375,023
2029	380,472	390,007	380,444	380,444
2030	385,903	395,537	385,874	385,874

Table 12.3-2A
48 State NOx Emission Reductions for Program Options 1 - 2

Year	Option 1	Option 1a	Option 1b	Option 2a	Option 2b	Option 2c	Option 2d	Option 2e
2000	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0
2008	0	0	0	301	301	301	301	0
2009	503	1	1	619	619	619	619	0
2010	1,766	5	5	1,007	2,098	2,374	1,007	0
2011	21,522	36,934	36,934	20,574	23,185	21,936	20,574	0
2012	52,597	115,220	115,220	52,218	54,809	53,563	52,218	0
2013	87,976	194,212	194,212	87,616	89,885	88,943	91,884	0
2014	153,004	273,046	273,046	152,680	154,892	153,963	161,257	0
2015	217,852	350,521	350,521	217,575	219,688	218,816	230,428	0
2016	281,454	423,557	423,557	281,270	283,278	282,407	306,499	0
2017	342,819	492,722	492,722	342,740	344,625	343,732	379,886	0
2018	399,696	554,913	554,913	399,692	401,369	400,568	448,475	0
2019	453,617	611,895	611,895	453,643	455,139	454,456	513,588	0
2020	503,665	663,626	663,626	503,701	505,133	504,416	573,519	0
2021	548,065	711,839	711,839	548,149	549,447	548,807	626,977	0
2022	588,591	756,359	756,359	588,685	589,871	589,253	676,038	0
2023	626,255	796,861	796,861	626,368	627,461	626,879	721,538	0
2024	660,995	834,447	834,447	661,122	662,142	661,590	762,962	0
2025	693,689	869,952	869,952	693,857	694,803	694,254	801,885	0
2026	723,546	902,739	902,739	723,762	724,582	724,056	837,483	0
2027	750,977	932,592	932,592	751,182	751,889	751,441	870,213	0
2028	776,413	959,480	959,480	776,574	777,232	776,816	900,551	0
2029	800,222	985,095	985,095	800,392	800,997	800,611	928,871	0
2030	821,736	1,009,757	1,009,757	821,911	822,382	822,114	954,589	0

Table 12.3-2B
48 State NOx Emission Reductions for Program Options 3 - 5

Year	Option 3	Option 4	Option 5a	Option 5b
2000	(0)	0	0	0
2001	(0)	0	0	0
2002	(0)	0	0	0
2003	(0)	0	0	0
2004	(0)	0	0	0
2005	(0)	0	0	0
2006	(0)	0	0	0
2007	(0)	0	0	0
2008	301	301	0	0
2009	619	619	0	0
2010	1,007	1,007	0	0
2011	15,943	20,574	19,175	19,175
2012	42,959	52,218	50,418	50,418
2013	73,685	87,616	81,973	81,973
2014	129,199	152,680	143,208	143,208
2015	184,630	217,575	204,359	204,359
2016	239,010	281,270	264,494	264,494
2017	291,695	342,740	322,902	322,902
2018	341,250	399,692	377,053	377,053
2019	388,195	453,643	428,369	428,369
2020	431,864	503,701	476,010	476,010
2021	471,461	548,149	518,543	518,543
2022	507,554	588,685	557,366	557,366
2023	541,378	626,368	593,437	593,437
2024	572,629	661,122	626,712	626,712
2025	602,207	693,857	658,107	658,107
2026	629,553	723,762	686,773	686,773
2027	654,659	751,182	713,101	713,101
2028	677,917	776,574	737,449	737,449
2029	699,765	800,392	760,270	760,270
2030	719,378	821,911	780,876	780,876

Table 12.3-3A
48 State PM2.5 Emission Reductions for Program Options 1 - 2

Year	Option 1	Option 1a	Option 1b	Option 2a	Option 2b	Option 2c	Option 2d	Option 2e
2000	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0
2006	0	0	11,805	10,394	0	0	0	0
2007	0	0	20,131	18,179	10,605	10,605	10,605	10,605
2008	11,630	11,969	20,513	19,061	19,061	19,061	19,061	19,061
2009	21,397	22,791	22,791	19,998	20,841	20,841	19,998	19,998
2010	24,225	29,437	29,437	21,864	24,363	24,236	21,864	21,864
2011	28,235	36,451	36,451	25,496	30,085	27,341	25,496	25,496
2012	33,664	43,747	43,747	31,233	36,723	33,151	31,233	31,233
2013	40,514	51,222	51,222	37,975	43,772	39,955	37,975	37,975
2014	47,663	58,464	58,464	45,139	51,005	47,128	45,139	45,139
2015	54,920	65,596	65,596	52,476	58,165	54,470	52,476	52,476
2016	62,027	72,326	72,326	59,682	65,096	61,539	59,682	59,682
2017	68,710	78,595	78,595	66,680	71,631	68,290	66,680	66,680
2018	75,009	84,351	84,351	73,288	77,749	74,714	73,288	73,288
2019	80,989	89,834	89,834	79,475	83,475	80,819	79,475	79,475
2020	86,591	94,962	94,962	85,254	88,803	86,448	85,254	85,254
2021	91,784	99,794	99,794	90,651	93,826	91,767	90,651	90,651
2022	96,713	104,398	104,398	95,702	98,536	96,669	95,702	95,702
2023	101,364	108,827	108,827	100,450	103,049	101,334	100,450	100,450
2024	105,799	113,021	113,021	104,977	107,373	105,794	104,977	104,977
2025	109,990	116,925	116,925	109,325	111,463	110,012	109,325	109,325
2026	113,855	120,414	120,414	113,414	115,223	113,904	113,414	113,414
2027	117,486	123,752	123,752	117,166	118,599	117,593	117,166	117,166
2028	120,883	126,976	126,976	120,557	121,819	120,955	120,557	120,557
2029	124,049	129,945	129,945	123,788	124,929	124,147	123,788	123,788
2030	127,107	132,829	132,829	126,910	127,826	127,239	126,910	126,910

Table 12.3-3B
48 State PM2.5 Emission Reductions for Program Options 3 - 5

Year	Option 3	Option 4	Option 5a	Option 5b
2000	0	0	0	0
2001	0	0	0	0
2002	0	0	0	0
2003	0	0	0	0
2004	0	0	0	0
2005	0	0	0	0
2006	0	0	0	0
2007	10,605	10,605	10,605	10,605
2008	19,003	19,060	18,240	18,796
2009	19,880	19,997	18,304	19,452
2010	21,685	22,206	19,211	21,003
2011	25,129	26,093	21,803	24,246
2012	30,676	31,835	26,572	29,607
2013	37,288	38,581	31,635	35,247
2014	44,181	45,748	37,094	41,268
2015	51,234	53,091	42,743	47,449
2016	58,148	60,303	48,364	53,523
2017	64,854	67,307	53,903	59,490
2018	71,216	73,919	59,112	65,101
2019	77,163	80,112	63,953	70,323
2020	82,718	85,896	68,458	75,189
2021	87,946	91,299	72,715	79,790
2022	92,842	96,357	76,700	84,096
2023	97,454	101,111	80,439	88,144
2024	101,858	105,645	84,033	92,020
2025	106,094	110,000	87,502	95,753
2026	110,095	114,096	90,771	99,270
2027	113,770	117,856	93,774	102,499
2028	117,089	121,254	96,444	105,389
2029	120,253	124,492	99,006	108,164
2030	123,309	127,621	101,490	110,855

Table 12.3-4A
Monitized Benefit Estimates for Program Options 1 - 2 (Millions of year 2000 dollars)

Year	**Option 1**	**Option 1a**	**Option 1b**	**Option 2a**	**Option 2b**	**Option 2c**	**Option 2d**	**Option 2e**
2000	$0	$0	$0	$0	$0	$0	$0	$0
2001	$0	$0	$0	$0	$0	$0	$0	$0
2002	$0	$0	$0	$0	$0	$0	$0	$0
2003	$0	$0	$0	$0	$0	$0	$0	$0
2004	$0	$0	$0	$0	$0	$0	$0	$0
2005	$0	$0	$0	$0	$0	$0	$0	$0
2006	$0	$0	$5,094	$4,497	$0	$0	$0	$0
2007	$0	$0	$8,935	$8,088	$4,701	$4,701	$4,701	$4,701
2008	$5,274	$5,425	$9,327	$8,564	$8,564	$8,564	$8,564	$8,563
2009	$9,719	$10,269	$10,269	$9,072	$9,456	$9,455	$9,072	$9,068
2010	$10,814	$12,159	$12,159	$10,015	$10,848	$10,820	$10,015	$10,009
2011	$13,300	$15,665	$15,665	$12,490	$13,786	$12,973	$12,490	$12,358
2012	$15,437	$18,777	$18,777	$14,794	$16,257	$15,308	$14,794	$14,441
2013	$18,260	$22,185	$22,185	$17,570	$19,156	$18,115	$17,600	$16,847
2014	$21,551	$25,736	$25,736	$20,845	$22,496	$21,409	$20,909	$19,604
2015	$25,056	$29,444	$29,444	$24,253	$26,000	$24,934	$24,454	$22,545
2016	$28,683	$33,182	$33,182	$27,891	$29,601	$28,547	$28,199	$25,474
2017	$32,398	$36,994	$36,994	$31,683	$33,297	$32,279	$32,104	$28,617
2018	$36,113	$40,742	$40,742	$35,478	$36,980	$36,029	$36,020	$31,752
2019	$39,932	$44,592	$44,592	$39,348	$40,741	$39,885	$40,019	$34,831
2020	$43,770	$48,453	$48,453	$43,231	$44,511	$43,731	$44,028	$38,007
2021	$47,512	$52,376	$52,376	$47,131	$48,315	$47,514	$48,055	$41,202
2022	$51,384	$56,343	$56,343	$51,034	$52,129	$51,376	$52,090	$44,294
2023	$55,290	$60,370	$60,370	$54,966	$55,903	$55,287	$56,155	$47,497
2024	$59,231	$64,426	$64,426	$58,933	$59,819	$59,237	$60,251	$50,725
2025	$62,916	$68,185	$68,185	$62,670	$63,477	$62,931	$64,013	$53,644
2026	$66,547	$71,759	$71,759	$66,382	$67,079	$66,572	$67,851	$56,637
2027	$70,056	$75,436	$75,436	$69,935	$70,498	$70,103	$71,630	$59,469
2028	$73,641	$79,121	$79,121	$73,515	$74,021	$73,675	$75,338	$62,322
2029	$77,201	$82,678	$82,678	$77,099	$77,565	$77,246	$78,950	$65,070
2030	$80,669	$86,372	$86,372	$80,591	$80,971	$80,728	$82,670	$67,929
NPV 2004	$550,024	$608,730	$625,176	$557,176	$565,879	$556,177	$559,522	$485,616
Delta from Proposal	$186	$58,892	$75,338	$7,338	$16,040	$6,339	$9,683	($64,222)

Table 12.3-4B

Monitized Benefit Estimates for Program Options 3 - 5

(millions of year 2000 dollars)

Year	Option 3	Option 4	Option 5a	Option 5b
2000	$0	$0	$0	$0
2001	$0	$0	$0	$0
2002	$0	$0	$0	$0
2003	$0	$0	$0	$0
2004	$0	$0	$0	$0
2005	$0	$0	$0	$0
2006	$0	$0	$0	$0
2007	$4,701	$4,701	$4,701	$4,701
2008	$8,551	$8,564	$8,378	$8,503
2009	$9,045	$9,071	$8,680	$8,943
2010	$9,973	$10,275	$9,390	$9,808
2011	$12,366	$12,800	$11,533	$12,161
2012	$14,585	$15,116	$13,555	$14,354
2013	$17,285	$17,905	$15,713	$16,691
2014	$20,303	$21,194	$18,434	$19,596
2015	$23,639	$24,717	$21,362	$22,710
2016	$27,091	$28,371	$24,422	$25,940
2017	$30,688	$32,179	$27,544	$29,335
2018	$34,303	$35,991	$30,766	$32,727
2019	$37,986	$39,879	$34,048	$36,183
2020	$41,682	$43,780	$37,340	$39,650
2021	$45,416	$47,599	$40,671	$43,057
2022	$49,156	$51,523	$44,011	$46,572
2023	$52,928	$55,476	$47,278	$50,116
2024	$56,638	$59,465	$50,689	$53,699
2025	$60,229	$63,222	$53,913	$57,080
2026	$63,807	$66,953	$57,123	$60,343
2027	$67,329	$70,527	$60,190	$63,659
2028	$70,679	$74,128	$63,286	$66,903
2029	$74,133	$77,733	$66,296	$70,063
2030	$77,493	$81,347	$69,418	$73,334
NPV 2004	$531,782	$556,114	$479,478	$507,053
Delta from Proposal	($18,056)	$6,276	($70,360)	($42,785)

Figure 12.3-1A
Monitized Benefit Estimates for Program Options 1 - 2 (millions of year 2000 dollars)

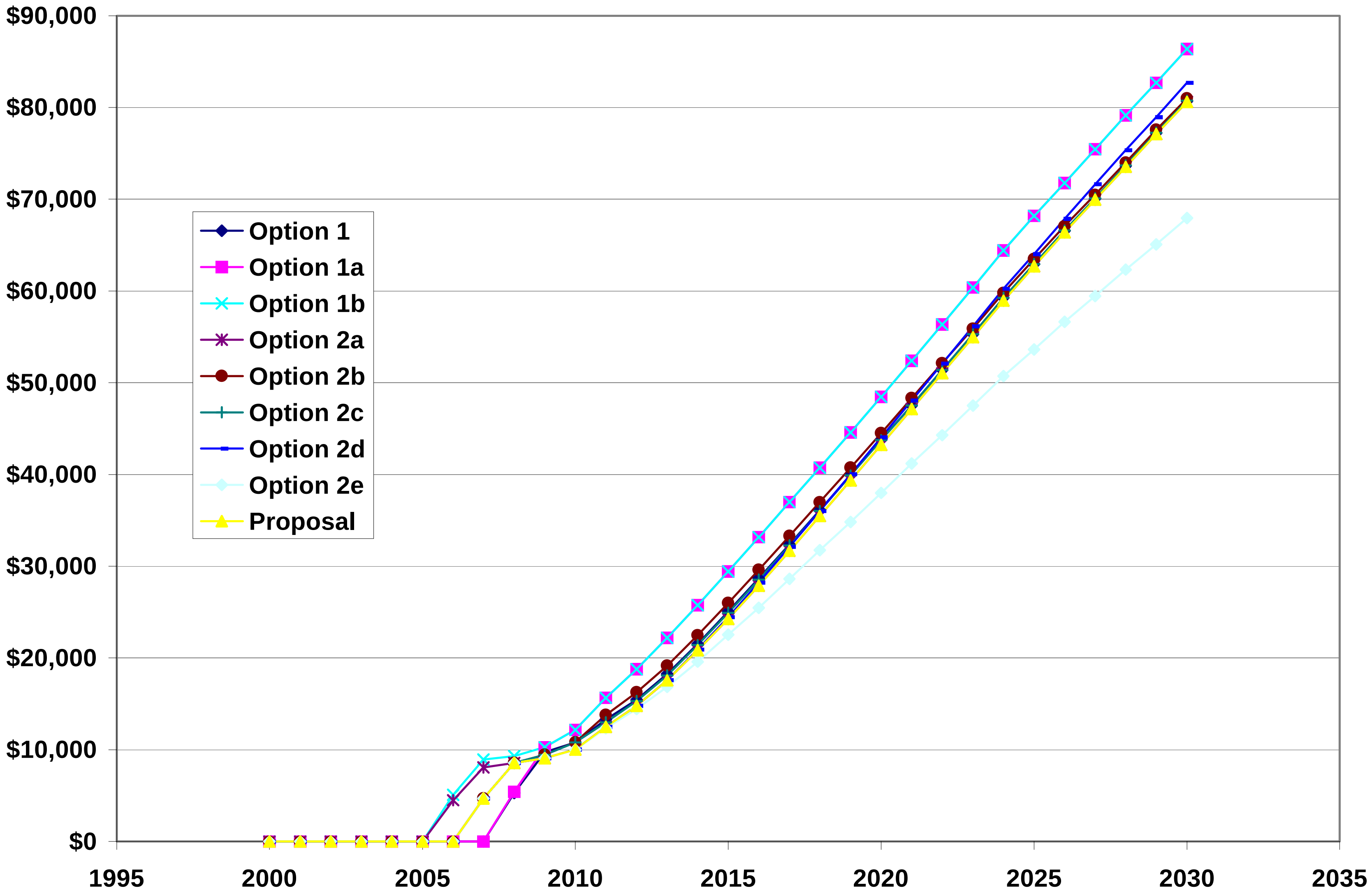


Figure 12.3-1B
Monitized Benefit Estimates for Program Options 3 - 5 (millions of year 2000 dollars)

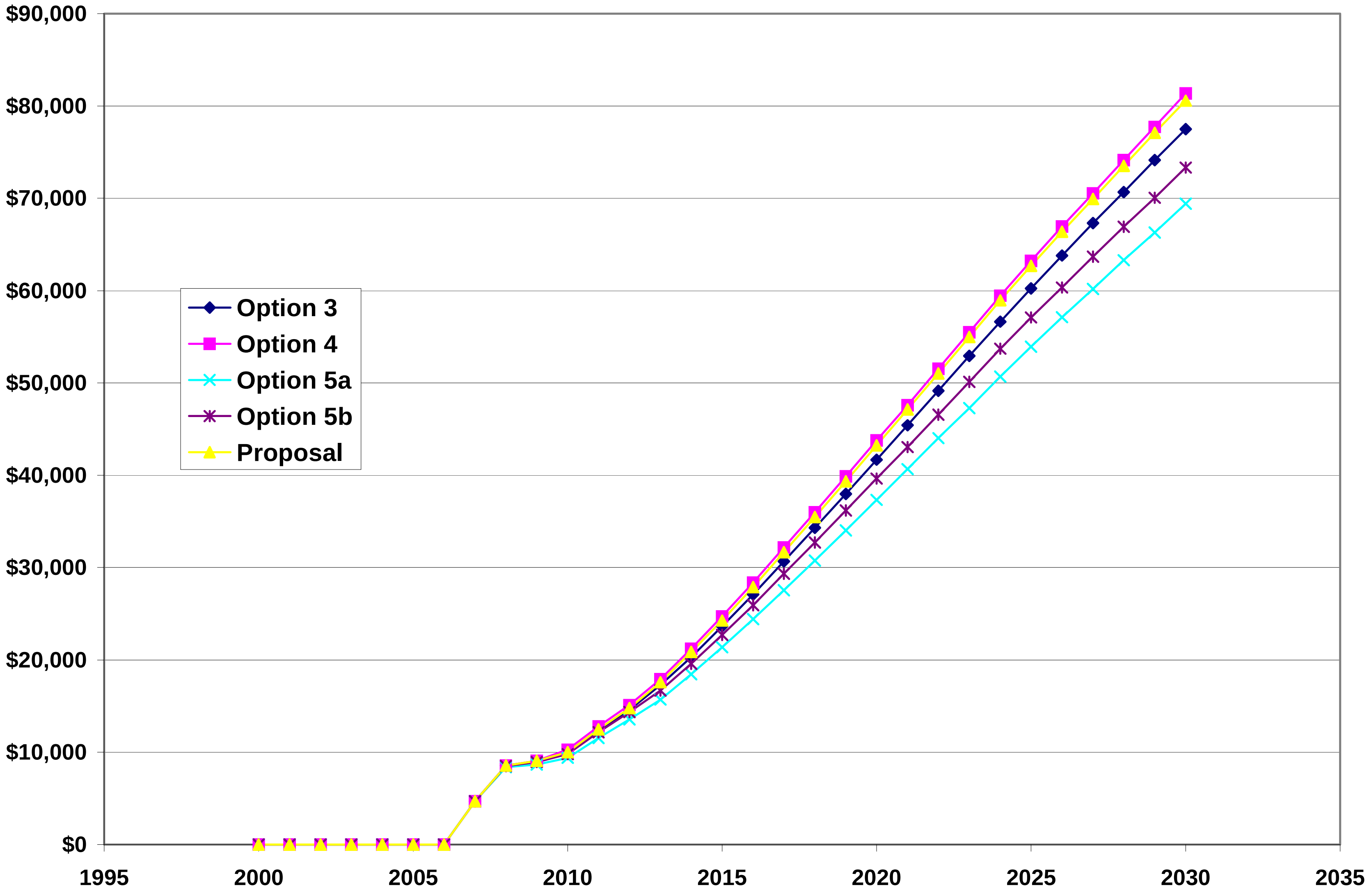


Table 12.3-5A
Benefit Increases for Options 1 - 2 Compared to Proposal (millions of year 2000 dollars)

Year	Option 1	Option 1a	Option 1b	Option 2a	Option 2b	Option 2c	Option 2d	Option 2e
2000	$0	$0	$0	$0	$0	$0	$0	$0
2001	$0	$0	$0	$0	$0	$0	$0	$0
2002	$0	$0	$0	$0	$0	$0	$0	$0
2003	$0	$0	$0	$0	$0	$0	$0	$0
2004	$0	$0	$0	$0	$0	$0	$0	$0
2005	$0	$0	$0	$0	$0	$0	$0	$0
2006	$0	$0	$5,094	$4,497	$0	$0	$0	$0
2007	-$4,701.5	-$4,701.5	$4,234	$3,387	$0	$0	$0	$0
2008	-$3,290	-$3,139	$763	$0	$0	$0	$0	-$2
2009	$647	$1,197	$1,197	$0	$385	$384	$0	-$3
2010	$799	$2,144	$2,144	$0	$833	$805	$0	-$6
2011	$809	$3,175	$3,175	$0	$1,295	$483	$0	-$133
2012	$642	$3,983	$3,983	$0	$1,463	$514	$0	-$353
2013	$690	$4,615	$4,615	$0	$1,586	$545	$30	-$723
2014	$706	$4,891	$4,891	$0	$1,651	$564	$64	-$1,241
2015	$802	$5,190	$5,190	$0	$1,746	$681	$201	-$1,708
2016	$792	$5,291	$5,291	$0	$1,710	$656	$308	-$2,417
2017	$715	$5,311	$5,311	$0	$1,615	$596	$421	-$3,065
2018	$635	$5,264	$5,264	$0	$1,502	$551	$542	-$3,726
2019	$584	$5,244	$5,244	$0	$1,393	$537	$670	-$4,517
2020	$539	$5,221	$5,221	$0	$1,280	$499	$796	-$5,224
2021	$382	$5,245	$5,245	$0	$1,185	$383	$924	-$5,929
2022	$349	$5,309	$5,309	$0	$1,095	$341	$1,056	-$6,741
2023	$324	$5,404	$5,404	$0	$936	$320	$1,189	-$7,469
2024	$298	$5,493	$5,493	$0	$885	$303	$1,318	-$8,208
2025	$245	$5,515	$5,515	$0	$807	$261	$1,343	-$9,026
2026	$165	$5,377	$5,377	$0	$696	$190	$1,468	-$9,745
2027	$121	$5,500	$5,500	$0	$563	$168	$1,695	-$10,467
2028	$126	$5,606	$5,606	$0	$505	$160	$1,823	-$11,193
2029	$102	$5,579	$5,579	$0	$466	$147	$1,851	-$12,029
2030	$78	$5,781	$5,781	$0	$381	$137	$2,079	-$12,662
NPV 2004	**$186**	**$58,892**	**$75,338**	**$7,338**	**$16,040**	**$6,339**	**$9,683**	**($64,222)**

Table 12.3-5B

Benefit Increases for Options 3 - 5 Compared to Proposal

(millions of year 2000 dollars)

Year	Option 3	Option 4	Option 5a	Option 5b
2000	$0	$0	$0	$0
2001	$0	$0	$0	$0
2002	$0	$0	$0	$0
2003	$0	$0	$0	$0
2004	$0	$0	$0	$0
2005	$0	$0	$0	$0
2006	$0	$0	$0	$0
2007	$0.0	$0.0	$0	$0
2008	-$13	$0	-$186	-$61
2009	-$27	$0	-$391	-$129
2010	-$42	$260	-$625	-$207
2011	-$124	$309	-$957	-$330
2012	-$209	$322	-$1,239	-$440
2013	-$285	$335	-$1,856	-$879
2014	-$542	$349	-$2,411	-$1,249
2015	-$615	$464	-$2,892	-$1,544
2016	-$800	$480	-$3,468	-$1,951
2017	-$995	$497	-$4,139	-$2,348
2018	-$1,175	$513	-$4,712	-$2,751
2019	-$1,362	$531	-$5,301	-$3,165
2020	-$1,550	$549	-$5,891	-$3,581
2021	-$1,714	$469	-$6,459	-$4,073
2022	-$1,879	$489	-$7,023	-$4,462
2023	-$2,038	$510	-$7,688	-$4,850
2024	-$2,296	$532	-$8,244	-$5,234
2025	-$2,441	$551	-$8,757	-$5,590
2026	-$2,575	$571	-$9,259	-$6,039
2027	-$2,606	$592	-$9,745	-$6,276
2028	-$2,836	$613	-$10,230	-$6,612
2029	-$2,966	$634	-$10,803	-$7,036
2030	-$3,098	$756	-$11,173	-$7,257
NPV 2004	**($18,056)**	**$6,276**	**($70,360)**	**($42,785)**

Figure 12.3-2A
Benefit Increases for Options 1 - 2 Compared to Proposal (millions of year 2000 dollars)

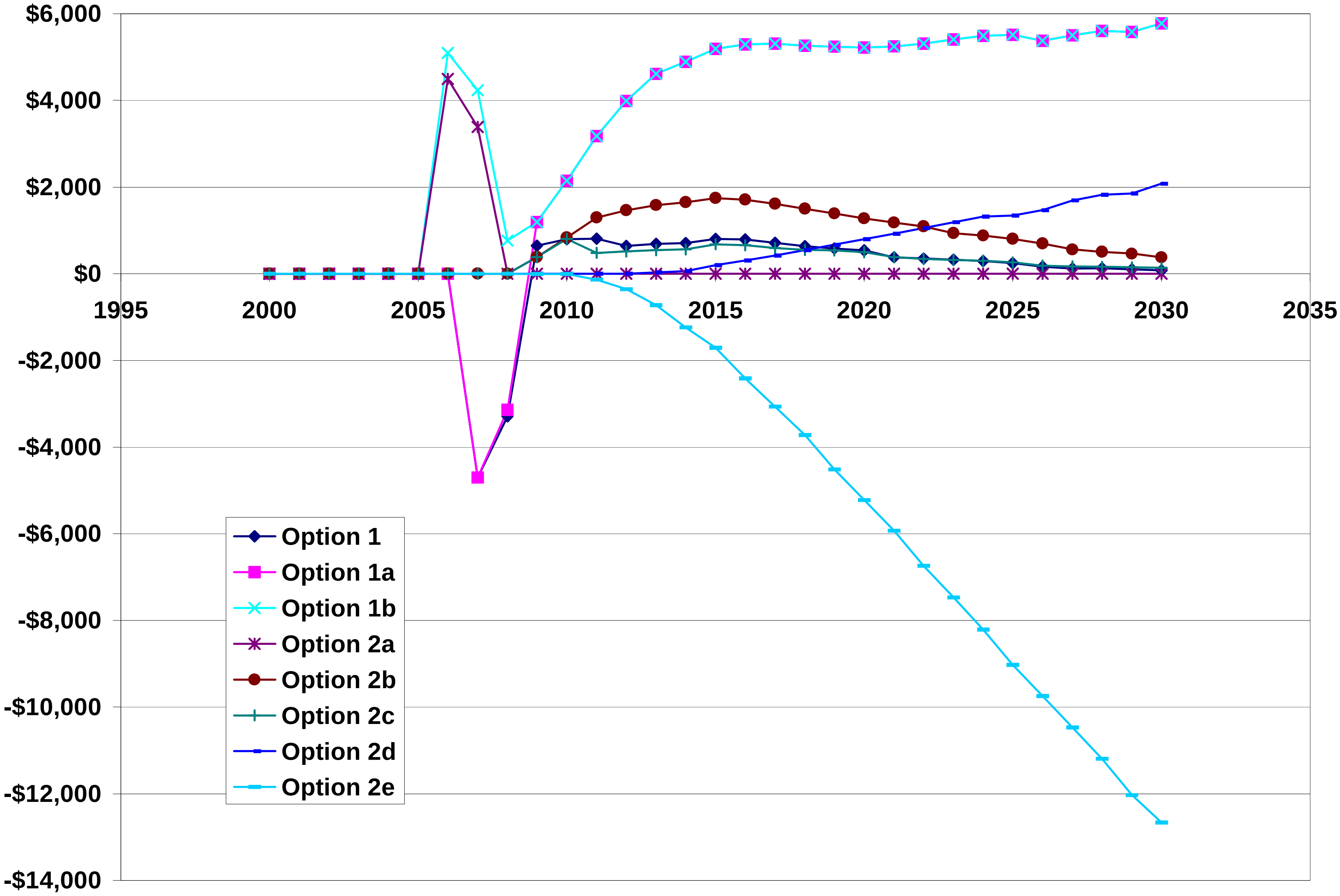
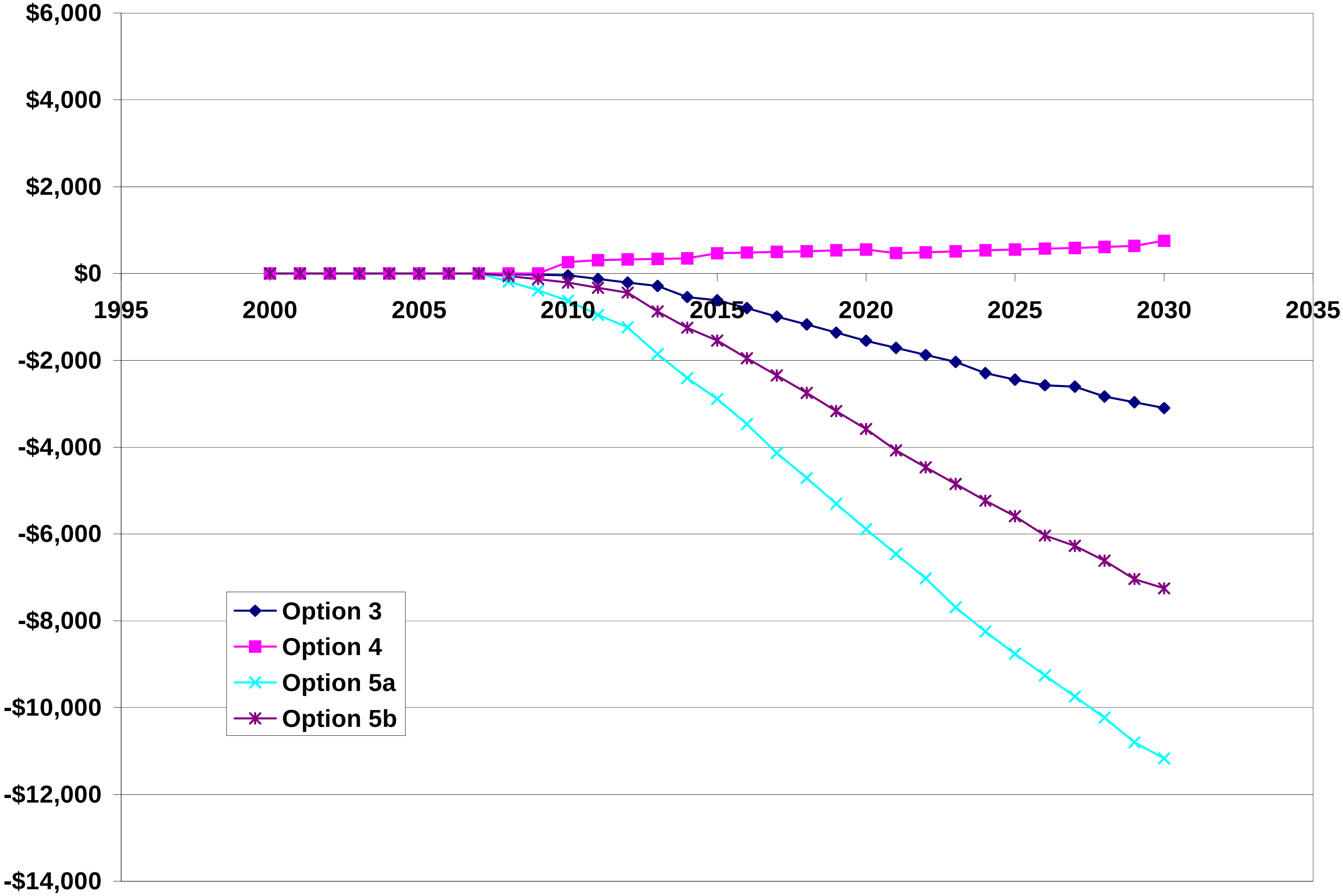


Figure 12.3-2B

Benefit Increases for Options 3 - 5 Compared to Proposal (millions of year 2000 dollars)



12.4 Cost Analysis for Alternative Options

This section describes the cost methodology and the estimates used to evaluate the alternative options. The section describes our estimates for both the fuel impacts and the engine/equipment impacts of the various options, if applicable.

The presentation of information on fuel costs is summarized in a series of tables showing the impact on a cost-per-gallon basis for the appropriate fuel alternative, as well as an estimate of the aggregate fuel cost impact for each alternative option. However, the detailed fuel cost analysis used to derive the cost-per-gallon estimates is contained in Chapter 7 of this draft RIA. The presentation of information on engine/equipment costs are detailed in the related sections below.

The engine and equipment cost estimates for the alternative options relies heavily on the methodology, and in some cases the estimates, used for the proposal. Our discussion of the cost estimates for the alternative options will focus on those inputs or methods which are different from the input or method used for the proposal. To the extent the cost estimates are based on the data used for the proposal, we have not repeated the analysis behind the estimate here, rather, the reader can refer to Chapter 6 of this draft RIA for the engine/equipment cost estimates for the proposal.

As noted in Chapter 3.1.5, there are differences in the fuel quantities used for costs and the fuel quantities used for emissions inventories resulting rom differences in methods. Please see Chapter 3.1.5 for additional discussion of these differences.

12.4.1 One Step Options

12.4.1.1 Option 1

This option is described in Figure 12.1.1-1 in Section 12.1 of this draft RIA. Option 1 requires 15ppm sulfur fuel in 2008 for nonroad engines only and 500 ppm sulfur fuel in 2008 for locomotive and marine engines, which allows early introduction of PM filter technology for some engines.

12.4.1.1.1 Fuel Costs for Option 1

The total fuel costs from Chapter 7 of the draft RIA comprising the refining and distribution and additive costs for Option 1 are summarized in the following tables.

Table 12.4.1.1.1-1
Per-Gallon Fuel Costs for Option 1 (cents per gallon)

Option	Specification	Year	Refining Costs (¢/gal)	Distribution & Additive Costs (¢/gal)	Total Costs (¢/gal)
One Step	15 ppm NR	2008 +	4.8	0.4	5.2
	500 ppm L & M	2008-2011	2.2	0.4	2.6
	500 ppm L & M	2012	2.2	0.2	2.4

Table 12.4.1.1.1-2
Net Operating Costs for Option 1 Incremental To The Proposal (millions)
(Net present values through 2030 at 3% discount rate)

Specification	Gallons	Fuel costs*	Net maintenance costs	Change in net operating costs
15 ppm fuel	11,530	$1,020	$250	$720
500 ppm fuel	-21,770	-$550		

* Note that the incremental fuel costs presented here are calculated as: [proposal $/gal] multiplied by [proposal gallons] minus the [option $/gal] multiplied by [option gallons]. This is not mathematically equivalent to the difference in gallons multiplied by the difference in $/gal.

These fuel costs and other related operating costs (i.e., maintenance savings) result in an increase in the net-present value of Option 1 of approximately $720 million as compared to the proposal through 2030.

12.4.1.1.2 Engine & Equipment Costs for Option 1

<u>Engine Fixed Costs</u>

As discussed in Section 12.6.2.1.1 of this draft RIA, Option 1 presents a number of unique challenges for engine manufacturers as compared to the proposal. These include up to two years of overlap with the nonroad Tier 3 development time frame and two fewer years of learning for the highway to nonroad technology transfer as compared to our proposal. These changes impact the engine engineering costs are described below. Because of these unique challenges, Option 1 has the potential to result in limited product offerings for certain segments of the nonroad engine and equipment market. This potential exists primarily because of the overlapping development time frames between Tier 3 and Tier 4. To the extent that engine and equipment manufacturers engineering staff and resources (e.g., sufficient laboratory test cells) are unable to cover both development programs, companies may need to decide to shift resources from one program to the other, with the result being limited product availability for either Tier 3 or possibly for Tier 4. Our cost analysis for Option 1 presented below assumes companies do have these resources. However, to the extent some companies do not have the necessary resources, our cost analysis does not attempt to estimate the cost impacts of limited product offerings.

Option 1 has significant overlap with Tier 3 engine development. Nonroad engine manufacturers typically require 3 to 4 years of development in advance of a major new emission standard or new engine product launch. This period allows for sufficient time for engine development as well as providing adequate time for equipment manufacturers to redesign equipment to accommodate the new technology engines. For the 175-750 hp category, a 2009 implementation could require engine development beginning as early as calender year 2005, which is also the final year of development before the Tier 3 implementation in 2006. There is also overlap with Option 1's 2010 implementation for the 100-175 hp category, which has a 2007 Tier 3 implementation. Finally, there would be two years of overlap under Option 1 for the 75-100 hp engines, which have a 2008 Tier 3 start date.

To estimate the cost impacts of these overlapping development programs, we have estimated that manufacturers would have sufficient staff to address the work load issues associated with product development of concurrent engine programs (i.e., development of Tier 3 and Tier 4 engines). This of course assumes that manufacturers have the additional staff to perform the concurrent engine development programs as well as the testing resources (e.g., laboratory capacity). It is possible that some manufactures do not have the personnel resources and/or the laboratory resources to cover both Tier 3 and Tier 4 engine development, and this cost analysis does not attempt to estimate what the impacts of such a short-fall would be. Based on our experience and discussions with engine manufacturers we have estimated that a typical product development group consists of 21 workers (9 engineers, 12 technicians). Our annual cost estimate for each team, including test cell time, is $3 million per year.[2] Therefore, for each year of potential overlap between the Tier 3 program and the Tier 4 program under Option 1 we have estimated an additional cost of $3 million per engine platform. Consistent with our estimation of the number of engine platforms in each power category used for the proposal, this would add approximately $290 million dollars to Option 1 as compared to the proposal.

The second impact on engine engineering costs of Option 1 is the reduced amount of time for nonroad engine companies to learn from the 2007 highway heavy-duty diesel experience with aftertreatment systems. There are a number of ways in which nonroad companies can learn from the extensive research and development effort being expended to achieve the 2007 highway standards. These include:

- nonroad engine companies can purchase 2007 highway products and reverse engineer how the products work;
- nonroad engine companies can learn from information available in the public literature regarding 2007 highway technologies (such as SAE papers and other technical publications);
- nonroad engine companies can learn by collaboration with technology vendors such as exhaust aftertreatment companies who are developing PM filters and NOx aftertreatment systems with on-highway companies;
- nonroad engine manufacturers can work with 3rd party engineering laboratories such as AVL, FEV, Ricardo, or Southwest Research Institute who through their work with

industry and governments will acquire significant expertise with diesel aftertreatment; and,
- nonroad engine companies can hire engineers and scientists away from highway companies who have already gone through the engine design experience.

In order to reduce costs for nonroad companies, they must have access to these various learning channels early enough in time to impact their R&D programs. For our proposal, which provides at least 4 years after the 2007 program before the first nonroad engines must use advanced aftertreatment systems, we have estimated this learning can reduce the R&D costs for nonroad companies by 30 percent compared to what they would incur if there was no 2007 highway program and the companies were required to develop the aftertreatment technologies without any learning from outside sources, and for nonroad companies who also are developing engines to comply with the 2007 highway standards we have estimated the learning time available with our proposal will reduce their R&D costs by 90 percent. We project based on our engineering judgement that as the time frame for learning is reduced below 4 years, the potential R&D cost reductions will decrease substantially, as shown in Table 12.4.1.1.2-1 below.

Table 12.4.1.1.2-1
Impact of Tier 4 Implementation of Engine Research and Development Costs

Company Type	Estimated Reduction in Tier 4 Engine R&D Costs as a Function of the First Year of Implementation for Nonroad Advanced Aftertreatment			
	2011 implementation	2010 implementation	2009 implementation	2008 implementation
Nonroad & Highway Companies	90 %	63%	14%	0%
Nonroad only companies	30 %	21%	5%	0%

Option 1 reduces the availability to learn from the highway program by two years for the 175 - 750 hp category. Based on the estimates provided in the table 12.4.1.1.2-1, this would reduce the learning for highway companies from 90 percent down to 14 percent, and for the nonroad only engine companies from 30 percent down to 5 percent. For the 75 - 175 hp category, Option 1 reduces the highway learning by one year. Based on the estimates provided in Table 12.4.1.1.2-1, this will reduce the learning for highway companies to 63 percent and for nonroad only companies to 21 percent. Consistent with the engine research and development costs estimated for the proposal and described in detail in Chapter 6 of this RIA, these adjustments increase the R&D expenditure of Option 1 by approximately $120 million dollars.

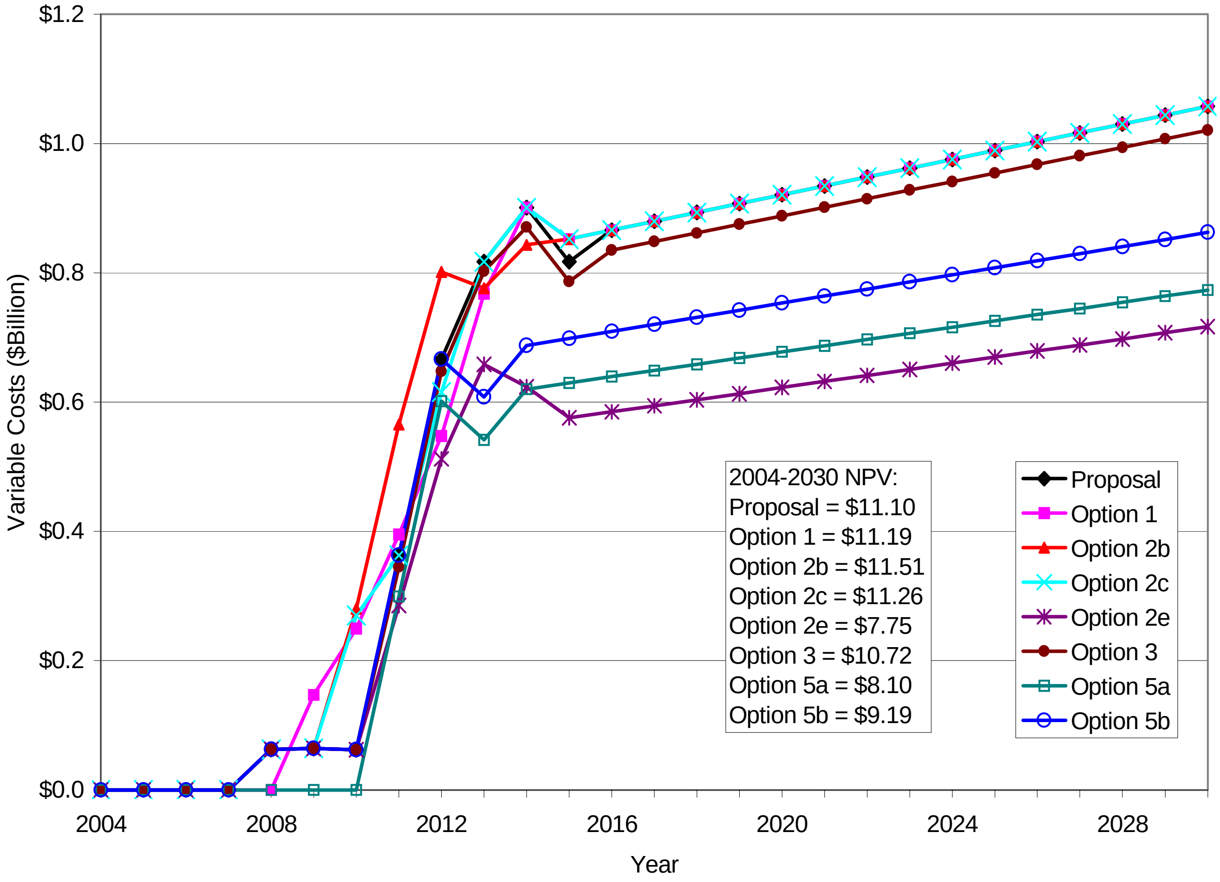
Engine Variable Costs

This option relies on the same engine hardware cost estimates as for the proposal, which are described in Chapter 6 of this draft RIA. Where appropriate, we have shifted the engine variable hardware costs in time to match the implementation dates of Option 1. Specifically:

- for the <50 hp category, the hardware costs described in Chapter 6 have been delayed by 1 year;
- for the 50-75 hp category, the 2008 transitional standard hardware has been eliminated;
- for the 75-175 hp category and the 175 - 750 hp category, the PM filter system hardware has been pulled forward by two years for 50 percent of the engines; and,
- for the >750 hp category, the hardware cost are the same as in the proposal.

The NPV of the engine variable costs through 2030 is approximately $90 million more than in the proposal. These costs are higher than the proposal because the elimination of the transitional PM standards for the 50-75 hp engines, combined with a 1 year delay in the standards for the < 50 hp engines does not off-set the increased hardware costs associated with the one year pull-ahead of PM filters for the 75 - 750 hp engines. The annual engine variable costs are shown in Figure Figure 12.4.1.1.2-1, along with the annual engine variable costs for the proposal and the other alternative options.

Figure 12.4.1.1.2-1. Engine Variable Costs for the Proposal and Alternative Options



Equipment Fixed Costs

Chapter 6 of this draft RIA presents a detailed discussion of our methodology for estimating equipment fixed costs, which is dominated by our estimates for equipment redesign costs. In this sub-section we will discuss the impact of Option 1 on the equipment fixed costs for each of the engine power categories.

For the <50 hp engine category there is a one year delay in the standards to 2009. We have not adjusted the costs to redesign the < 50 hp engines, but we have shifted the costs back by one year in time.

For the 50-75 hp engine category, Option 1 eliminates the 2008 transitional PM standards, and we have eliminated the equipment redesign costs associated with the proposed 2008 transitional standard.

For the 75 - 175 hp engine category, Option 1 pulls ahead the proposed 0.01 g/bhp-hr PM standard ahead by two years to 2010 for 50 percent of the engines. This is followed by 50 percent of the engines meeting the proposed PM and NOx standard in 2012, and finally 50 percent of the engines must meet the final NOx standard. Therefore, we have estimated Option 1 will require a major equipment redesign for 50 percent of the engines 3 times (2010, 2012 and 2014), or a total of 1.5 redesigns for the power category. In effect, this is one-quarter more redesigns than expected under the proposal which increases redesign costs by approximately $470 million.

Equipment Variable Costs

We have estimated the impacts on equipment variable costs in the same manner as done for engine variable costs by eliminated costs where appropriate and shifting them up a year or two or back a year or two where appropriate. These changes increase the NPV through 2030 by approximately $20 million relative to the equipment variable costs expected under the proposal.

Total Engine/Equipment Cost

Based on the estimates provided above, we have estimated the Option 1 will result in an increase in the net-present value of the engine and equipment costs through 2030 of approximately $990 million dollars.

12.4.1.2 Option 1a

Option 1a is described in Figure 12.1.1-2 in Section 12.1 of this draft RIA. Option 1a requires 15ppm sulfur fuel in 2008 for nonroad, locomotive and marine engines. The engine standards, which are also described in Chapter 12.1, consist of a 2 year introduction for a 0.01 g/bhp-hr PM standard for all nonroad engines by power category beginning in 2009, and a two year introduction of a 0.30 g/bhp-hr NOx standard for all nonroad engines by power category beginning in 2011.

As discussed in Section 12.6.2.1.2, we do not believe this very aggressive standards program is technically feasible for either the fuel program or the engine program, and therefore we have not provided a cost estimate for Option 1a.

12.4.1.3 Option 1b

Option 1b is described in Figure 12.1.1-3 in Section 12.1 of this draft RIA. Option 1b has the same engine standards as Option 1a; however, the fuel program consists of 15ppm for nonroad, locomotive and marine engines beginning in 2006. Option 1b is identical to Option 1a with respect to the engine standards program, and the fuel program is implemented two years earlier in 2006. As discussed in Section 12.6.2.1.3, we do not believe this very aggressive standards program is technically feasible for either the fuel program or the engine program, and therefore we have not provided a cost estimate for Option 1b.

12.4.2 Two Step Options

12.4.2.1 The Proposal

Our fuel and engine standards proposal is summarized in Figure 12.1.2-1 in Section 12.1 of this draft RIA. The cost estimation for the proposal is detailed in Chapters 6 (engine & equipment program) and 7 (fuel program) of this draft RIA, and will not be repeated here.

12.4.2.2 Option 2a

Option 2a is described in Figure 12.1.2-2 in Section 12.1 of this draft RIA. Option 2a requires the same engine program as our proposal; however, the first-step of the two step fuel program (500 ppm sulfur fuel for nonroad, locomotive and marine engines) is implemented one year earlier than in our proposal (2006 rather than 2007).

As discussed in Section 12.6.2.2.2, we do not believe this aggressive fuel program is technically feasible and therefore we have not provided a cost estimate for Option 2a.

12.4.2.3 Option 2b

This option is described in Figure 12.1.2-3 in Section 12.1 of this draft RIA. Option 2b is similar to the fuel program for the proposal, except the 15 ppm sulfur nonroad fuel is pulled ahead one year to 2009. The engine standards program under Option 2b is similar to the proposal, except that the PM filter based standards for the >25 hp engines is pulled forward by one year, however the NOx program and the 2008 PM standards for the <75 hp engines are the same as the proposal.

12.4.2.3.1 Fuel Costs for Option 2b

The total fuel costs from Chapter 7 of the Draft RIA comprising the refining and distribution and additive costs for Option 2b are summarized in the following tables.

Table 12.4.2.3.1-1
Total Fuel Costs for Option 2b (cents per gallon)

Option	Specification	Year	Refining Costs (¢/gal)	Distribution & Additive Costs (¢/gal)	Total Costs (¢/gal)
Nonroad goes to 15 ppm in 2009	500 ppm NR, L & M	2007-2008	2.2	0.3	2.5
	500 ppm L & M	2009-2012	2.2	0.4	2.6
	15 ppm NR (total incl 2007)	2009+	4.6	0.4	5.0
	500 ppm L & M	2013+	2.2	0.2	2.4

Table 12.4.2.3.1-2
Net Operating Costs for Option 2b Incremental To The Proposal (millions)
(Net present values through 2030 at 3% discount rate)

Specification	Gallons	Fuel costs*	Net maintenance costs	Total operating costs
15 ppm fuel	4,270	$430	$250	$540
500 ppm fuel	-5,180	-$130		

* Note that the incremental fuel costs presented here are calculated as: [proposal $/gal] multiplied by [proposal gallons] minus the [option $/gal] multiplied by [option gallons]. This is not mathematically equivalent to the difference in gallons multiplied by the difference in $/gal.

These fuel costs and other related operating costs (e.g., maintenance savings, fuel consumption impacts) result in an increase in the net-present value of Option 2b of approximately $540 million as compared to the proposal through 2030.

12.4.2.3.2 Engine and Equipment Costs for Option 2b

Engine Fixed Costs

As discussed in Section 12.6.2.2.3, Option 2b presents a number of unique challenges for engine manufacturers as compared to the proposal. These include up to one year of overlap with the nonroad Tier 3 development time frame for one power category, and one less year for learning for the highway to nonroad technology transfer as compared to our proposal. In addition, Option 2b presents a significant challenge for engine manufacturers during the implementation of the standards for NOx and PM in the 2010-2013 time frame which is not present in our proposal. Specifically, engines >25 hp will have a series of introductions with new PM standards one year and new NOx standards the next year. We have estimated a cost impact for each of these engine engineering impacts as compared to our proposal, as described below. Because of these unique challenges, Option 2b has the potential to result in limited product offerings for certain segments of the nonroad engine and equipment market. This potential exists primarily from the rapid change in PM and NOx standards for the same engine power categories in the 2010-2013 time frame, as well as the overlapping development time frames between Tier 3 and Tier 4. To the extent that engine and equipment manufacturers engineering staff and resources (e.g., sufficient laboratory test cells) are not sufficient to address the workload issues associated with these engineering requirements, companies may need to decide to focus their resources on certain products at the expense of others, with the result being limited product availability for Tier 3 as well as for Tier 4. Our cost analysis for Option 2b presented below assumes companies do have these resources. However, to the extent some companies do not have the necessary resources, our cost analysis does not attempt to estimate the cost impacts of limited product offerings.

Option 2b has up to one year of engine design overlap with Tier 3 engine development, specifically for engines in the 75 - 100 hp range. For these engines, Tier 3 is implemented in 2008, and Option 2b's one year pull-ahead of PM standards would begin in 2011. As discussed in Section 12.4.1.1.2 (Engine & Equipment Costs for Option 1), nonroad engine manufacturers typically require 3 to 4 years of development in advance of a major new emission standard or new engine product launch. As discussed in Section 12.4.1.1.2, we have estimated this potential overlap in Tier 3 and Tier 4 engine development could cost on the order of $3 million per engine platform. Consistent with our estimation of the number of engine platforms in each power category used for the proposal, this adds approximately $30 million dollars to Option 2b as compared to the proposal.

The second impact on engine engineering costs of Option 2b is the reduced amount of time for nonroad engine companies to learn from the 2007 highway heavy-duty diesel experience with aftertreatment systems. Compared to our proposal, Option 2b reduces this time frame by one year because of the pull-ahead of the PM filter based standards. As discussed in Section 12.4.1.1.2 and using the estimates provided in Table 12.4.1.1.2-1, Option 2b will reduce the engine research and development cost savings due to learning for highway companies from 90 to 63 percent and for nonroad only companies from 70 to 21 percent. Consistent with the engine research and development costs estimated for the proposal and described in detail in Chapter 6 of this RIA, these adjustments increase the R&D expenditure of Option 2b by approximately $40 million dollars.

The third impact of Option 2b on the engine engineering costs is the rapid change of PM and NOx standards in two years for both the 75-175 hp and 175-750 hp categories. Option 2b implements a 0.01 g/bhp-hr PM standard in 2010 for 100 percent of the engines, and the following year 50 percent of the engines must meet a 0.30 g/bhp-hr NOx standard, therefore ½ of the engines will require a redesign in 2009 and 2010. This will present a significant engine calibration challenge for engine manufacturers. Under Option 2b, we are projecting that in order to comply with the requirement to produce 50 percent of the engines to a new standard the next year, companies would need to expend considerable engineering resources (staff and test cell time) to develop the new calibrations. We have estimated that each engine platform would require a team of 3 engineers and 4 technicians plus laboratory test cell resources working for one year to develop the additional calibrations which Option 2b would require (implementation of Tier 4 NOx standards 1 year after Tier 4 PM standards for ½ of the engines). We estimate the cost of this team for one year at $1 million.[3] Consistent with our estimation of the number of engine platforms in each power category used for the proposal, this engineering effort ($1 million per engine platform for ½ of the platforms in the 75-750 hp categories) adds approximately $30 million dollars to Option 2b as compared to the proposal.

Engine Variable Costs

Option 2b relies on the same engine hardware cost estimates as for the proposal, which are described in Chapter 6 of this draft RIA. Where appropriate, we have shifted the engine variable hardware costs in time to match the implementation dates of Option 2b. Specifically:

- for the >25 hp engines, 75-175 hp category and the 175 - 750 hp category, the PM filter system hardware has been pulled forward by one year
- for the >750 hp category, the PM filter system has been pulled forward by one year for 50 percent of the engines.

The NPV of the engine variable costs through 2030 is approximately $410 million more than the proposal. The annual engine variable costs are shown in Figure 12.4.1.1.2-1.

Equipment Fixed Costs

Chapter 6 of this draft RIA presents a detailed discussion of our methodology for estimating equipment fixed costs, which is dominated by our estimates for equipment redesign costs. In this sub-section we will discuss the impact of Option 2b on the equipment fixed costs for each of the engine power categories.

For the <25 hp engine category, Option 2b is the same as the proposal, so there are no differences for equipment redesign costs.

For the 25-50 hp engines, Option 2b would require a redesign in 2012 for PM filters , followed by a minor equipment update the next year to accommodate the 3.5 g/bhp-hr NOx standard. We have estimated the 2012 equipment redesign costs as being equivalent to the redesign costs of the proposal's 2013 program. We have estimated the cost of Option 2b's 2013 NOx standard impact as being ½ of the redesign costs of the proposal's 2013 costs.

For the 50-75 hp engines, Option 2b requires equipment redesign one year earlier than in the proposal. However, we estimate the equipment redesign effort is identical to the proposal, and we have estimated the costs to be the same as the proposal.

For the 75 - 175 hp engine category, Option 2b pulls ahead the proposed 0.01 g/bhp-hr PM standard ahead by one year to 2011. This is followed by 50 percent of the engines meeting the proposed NOx standard in 2012, and finally 50 percent of the engines must meet the final NOx standard in 2014. Therefore, we have estimated Option 2b will require a major equipment redesign for all of the equipment in 2011, followed by a minor redesign effort in 2012 for 50 percent of the equipment and in 2014 for 50 percent of the equipment. We have estimated that each of these minor redesign efforts will cost ½ of the major redesign costs estimated for the proposal.

For the 175 - 750 hp engine category, Option 2b pulls ahead the proposed 0.01 g/bhp-hr PM standard ahead by one year to 2010. This is followed by 50 percent of the engines meeting the proposed NOx standard in 2011, and finally 50 percent of the engines must meet the final NOx standard in 2014. Therefore, we have estimated Option 2b will require a major equipment redesign for all of the equipment in 2010, followed by a minor redesign effort in 2011 for 50 percent of the equipment and in 2014 for 50 percent of the equipment. We have estimated that each of these minor redesign efforts will cost ½ of the major redesign costs estimated for the proposal.

For the > 750 hp category, Option 2b pulls ahead the proposed 0.01 g/bhp-hr PM standard ahead by one year to 2010 for 50 percent of the engines. This is followed by 50 percent of the engines meeting the proposed NOx standard in 2011, and finally all of the engines must meet the final PM and NOx standard in 2014. We have estimated that the equipment which goes through a major redesigned to accommodate the new PM standard engines in 2010 will not redesign again until 2014, when they would go through a minor equipment redesign related to the NOx standard. The other half of the equipment fleet would go through a major redesign in 2011 to accommodate the NOx standard, and this same equipment would also go through a minor redesign in 2014 to meet the final PM standard. Consistent with the discussion above, we have estimated the costs of the major redesign to be equivalent to the redesign estimates for the proposal, and we have estimated that a minor redesign costs ½ of the proposal's major redesign estimates.

The combined result of the changes listed above for the equipment fixed costs result in an increase for Option 2b as compared to our proposal of approximately $130 million.

Equipment Variable Costs

We have estimated the impacts on equipment variable costs in the same manner as done for engine variable costs by eliminated costs where appropriate and shifting them up a year or two or back a year or two where appropriate. These changes increase the NPV through 2030 by $10 million relative to the equipment variable costs expected under the proposal.

Total Engine/Equipment Cost

Based on the estimations provided above, we have estimated the Option 2b will result in an increase in the net-present value of the engine and equipment costs through 2030 of approximately $640 million dollars.

12.4.2.4 Option 2c

This option is described in Figure 12.1.2-4 in Section 12.1 of this draft RIA. Option 2c is almost identical to Option 2b which is described in section 12.4.2.3 above, with the exception that the one year pull ahead of the PM standard is only for the 175-750 hp engine category (Option 2b pulls ahead the PM filter based standard for all engines >25 hp by one year). As with Option 2b, this will require 15 ppm sulfur nonroad fuel in 2009, one year earlier than in the proposal.

12.4.2.4.1 Fuel Costs for Option 2c

The total fuel costs from Chapter 7 of the Draft RIA comprising the refining and distribution and additive costs for Option 2c are summarized in the following tables. These tables are the same as in Option 2b.

Table 12.4.2.4.1-1
Total Fuel Costs for Option 2c (cents per gallon)

Option	Specification	Year	Refining Costs (¢/gal)	Distribution & Additive Costs (¢/gal)	Total Costs (¢/gal)
Nonroad goes to 15 ppm in 2009	500 ppm NR, L & M	2007-2008	2.2	0.3	2.5
	500 ppm L & M	2009-2012	2.2	0.4	2.5
	15 ppm NR (total incl 2007)	2009+	4.6	0.4	5.0
	500 ppm L & M	2013+	2.2	0.2	2.4

Table 12.4.2.4.1-2
Net Operating Costs for Option 2c Incremental To The Proposal (millions)
(Net present values through 2030 at 3% discount rate)

Specification	Gallons	Fuel costs*	Net maintenance costs	Total operating costs
15 ppm fuel	4,270	$430	$240	$530
500 ppm fuel	-5,180	-$130		

* Note that the incremental fuel costs presented here are calculated as: [proposal $/gal] multiplied by [proposal gallons] minus the [option $/gal] multiplied by [option gallons]. This is not mathematically equivalent to the difference in gallons multiplied by the difference in $/gal.

These fuel costs and other related operating costs (e.g., maintenance savings, fuel consumption impacts) result in an increase in the net-present value of Option 2c of approximately $530 million as compared to the proposal through 2030.

12.4.2.4.2 Engine and Equipment Costs for Option 2c

Engine Fixed Costs

As discussed in Section 12.6.2.2.4, Option 2c represents a number of unique challenges for engine and manufacturers as compared to the proposal (these challenges are very similar to those for Option 2b, but only for those engines and equipment in the 175-750 hp category). As discussed in Section 12.4.2.3.2 (Option 2b), to the extent that engine and equipment manufacturers engineering staff and resources are not sufficient to address the workload issues associated with these engineering requirements, companies may need to decide to focus their resources on certain products at the expense of others, with the result being limited product availability for Tier 3 as well as for Tier 4. Our cost analysis for Option 2c presented below assumes companies do have these resources. However, to the extent some companies do not have the necessary resources, our cost analysis does not attempt to estimate the cost impacts of limited product offerings.

Option 2c reduces the amount of time for nonroad engine companies to learn from the 2007 highway heavy-duty diesel experience with aftertreatment systems. Compared to our proposal, Option 2c reduces this time frame by one year because of the pull-ahead of the PM filter based standards for the 175-750 hp engine category. As discussed in Section 12.4.1.1.2 and using the estimates provided in Table 12.4.1.1.2-1, Option 2c will reduce the engine research and development cost savings due to learning for highway companies from 90 to 63 percent and for nonroad only companies from 70 to 21 percent. Consistent with the engine research and development costs estimated for the proposal and described in detail in Chapter 6 of this RIA, these adjustments increase the R&D expenditure of Option 2c by approximately $40 million dollars.

As discussed under Option 2b, Option 2c also increases the engine engineering costs relative to the proposal due to the rapid change of PM and NOx standards in two years. For the 175-750 hp category, Option 2c implements a 0.01 g/bhp-hr PM standard in 2010 for 100 percent of the engines, and the following year 50 percent of the engines must meet a 0.30 g/bhp-hr NOx standard, therefore ½ of the engines will require a redesign in 2009 and 2010. This will present a significant engine calibration challenge for engine manufactures. Under Option 2c, we are projecting that in order to comply with the requirement to produce 50 percent of the engines to a new standard the next year, companies would need to expend considerable engineering resources (staff and test cell time) to develop the new calibrations. We have estimated that each engine platform would require a team of 3 engineers and 4 technicians plus laboratory test cell resources working for one year to develop the additional calibrations which Option 2c would require (implementation of Tier 4 NOx standards 1 year after Tier 4 PM standards for ½ of the engines).

We estimate the cost of this team for one year at $1 million.[4] Consistent with our estimation of the number of engine platforms in each power category used for the proposal, this engineering effort ($1 million per engine platform for ½ of the platforms in the 175-750 hp category) adds approximately $20 million dollars to Option 2c as compared to the proposal.

Engine Variable Costs

Option 2c relies on the same engine hardware cost estimates as for the proposal, which are described in Chapter 6 of this draft RIA. Where appropriate, we have shifted the engine variable hardware costs in time to match the implementation dates of Option 2c. Specifically for 175 - 750 hp category, the PM filter system hardware has been pulled forward by one year. The NPV of the engine variable costs through 2030 is approximately $160 million more than the proposal. The annual engine variable costs are shown in Figure 12.4.1.1.2-1.

Equipment Fixed Costs

Chapter 6 of this draft RIA presents a detailed discussion of our methodology for estimating equipment fixed costs, which is dominated by our estimates for equipment redesign costs. In this sub-section we will discuss the impact of Option 2c on the equipment fixed costs for the 175-750 hp category equipment.

For the 175 - 750 hp engine category, Option 2b pulls ahead the proposed 0.01 g/bhp-hr PM standard ahead by one year to 2010. This is followed by 50 percent of the engines meeting the proposed NOx standard in 2011, and finally 50 percent of the engines must meet the final NOx standard in 2014. Therefore, we have estimated Option 2b will require a major equipment redesign for all of the equipment in 2010, followed by a minor redesign effort in 2011 for 50 percent of the equipment and in 2014 for 50 percent of the equipment. We have estimated that each of these minor redesign efforts will cost ½ of the major redesign costs estimated for the proposal. Compared to the proposal, Option 2b increases the equipment redesign costs for the 75-175 hp category by approximately $70 million.

Equipment Variable Costs

We have estimated the impacts on equipment variable costs in the same manner as done for engine variable costs by eliminated costs where appropriate and shifting them up a year or two or back a year or two where appropriate. These changes increase the NPV through 2030 by $10 million relative to the equipment variable costs expected under the proposal.

Total Engine/Equipment Cost

Based on the estimations provided above, we have estimated the Option 2b will result in an increase in the net-present value of the engine and equipment costs through 2030 of approximately $300 million dollars.

12.4.2.5 Option 2d

This option is described in Figure 12.1.2-5 in Section 12.1 of this draft RIA. Option 2d is the same as the proposal but with the addition of a 0.30 g/bhp-hr NOx standard applied to engines in the 25-75 hp category. These NOx standards would be phased in over three years from 2013 through 2015. Option 2d has the same fuel program as the proposal.

As discussed in Section 12.6.2.2.5, we do not believe a 0.30 g/bhp-hr NOx standard is appropriate for engines in this power category, and therefore we have not provided a cost estimate for Option 2d.

12.4.2.6 Option 2e

This option is described in Figure 12.1.2-6 in Section 12.1 of this draft RIA. Option 2e requires the same PM standards and implementation schedule as the proposal, but there are no Tier 4 NOx standards. Option 2e has the same fuel program as the proposal.

12.4.2.6.1 Fuel Costs for Option 2e

Option 2e has no changes in the fuel program compared to our proposal, therefore the estimated fuel costs (e.g., the cents/gallon estimates) are no different from the proposal. However, the elimination of the NOx standard does impact our fuel consumption impacts. As discussed in Chapter 6.2.3 of this draft RIA (Engine Operating Costs), a combined NOx adsorber - PM filter system can result in a net increase in fuel consumption of as much as one percent, while a PM filter only system can result in a net increase in fuel consumption of as much as two percent. Therefore, removal of the NOx control program results in an increase in the operating costs of Option 2e as compared to our proposal. The net present value of this increase through 2030 is approximately $460 million.

12.4.2.6.2 Engine and Equipment Costs for Option 2e

Engine Fixed Costs

Option 2e requires no NOx related fixed costs as compared to our proposal. Eliminating these costs reduces the cost of Option 2e relative to our proposal by approximately $130 million.

Engine Variable Costs

Option 2e removes any new NOx related variable costs from the program. The NPV of the engine variable costs for Option 2e through 2030 is approximately $3.4 billion less than the proposal. The annual engine variable costs are shown in Figure 12.4.1.1.2-1.

Equipment Fixed Costs

We have estimated that Option 2e has a minimal impact on the equipment redesign costs compared to the proposal because the equipment manufacturers will be modifying their products in order to add PM filters under Option 2e, and we believe there are minimal differences for equipment manufacturers for packaging a NOx adsorber and a PM filter as compared to packaging only a PM filter. However, the proposal does include a minor redesign cost estimate for 50 percent of the equipment in the 75-750 hp categories in 2014 due to the implementation of the 0.30 g/bhp-hr NOx standard for ½ of the engines. We have eliminated this cost from Option 2e. Compared to the proposal, Option 2e reduces the equipment redesign costs by approximately $120 million.

Equipment Variable Costs

Option 2e removes any new NOx related variable costs from the program. The NPV of the equipment variable costs for Option 2e through 2030 would be approximately $170 million less than the proposal due to less sheet metal required to house exhaust emission control devices and fewer bolts and brackets needed to secure those devices.

Total Engine/Equipment Cost

Based on the estimations provided above, we have estimated the Option 2e will result in a decrease in the net-present value of the engine and equipment costs through 2030 of approximately $3.8 billion dollars.

12.4.3 Other Options

12.4.3.1 Option 3

This option is described in Figure 12.1.2-7 in Section 12.1 of this draft RIA. Option 3 imposes no Tier 4 standards for engines used in above-ground mining equipment (AGME). Option 2e has the same fuel program as the proposal.

12.4.3.1.1 Fuel Costs for Option 3

Option 2e has no changes on the cost of fuel relative to our proposal. However, the operating costs for AGME are lower than in our proposal due to the elimination of PM filter maintenance requirements and our estimate of a one percent fuel consumption increase due to PM filters. This results in a decrease in the net-present value of Option 3 of approximately $80 million as compared to the proposal through 2030.

12.4.3.1.2 Engine and Equipment Costs for Option 3

Mining equipment is defined for this analysis as certain equipment types over 750hp as described in Section 12.6.2.2.7 of this draft RIA. This includes equipment types such as excavators, off highway trucks, wheel loaders, crawler tractor/dozers and off-highway tractors.

Engine Fixed Costs

Because these engines are used in equipment other than the AGME, Option 3 has no impact on the engine fixed costs.

Engine Variable Costs

We have removed the variable costs associated with the Tier 4 proposal from the AGME engines (i.e., PM filters and NOx adsorbers) to evaluate the impact of Option 3. The NPV of the engine variable costs for Option 3 through 2030 is approximately $380 million less than the proposal. The annual engine variable costs are shown in Figure 12.4.1.1.2-1.

Equipment Fixed Costs

Option 3 would remove any equipment redesign requirements for the AGME. This reduces the costs of Option 3 by approximately $10 million relative to the proposal.

Equipment Variable Costs

We have eliminated the equipment variable costs for the >750 hp AGME for Option 3. These changes reduce the NPV through 2030 by approximately $20 million relative to the equipment variable costs expected under the proposal.

Total Engine/Equipment Cost

Based on the estimations provided above, we have estimated that Option 3 would result in a decrease in the net-present value of the engine and equipment costs through 2030 of approximately $410 million dollars.

12.4.3.2 Option 4

Option 4 is described in Figure 12.1.2-8 in Section 12.1 of this draft RIA. Option 4 is similar to the proposal, but it requires locomotive and marine diesel fuel sulfur levels to be controlled to a level of 15ppm in 2010.

12.4.3.2.1 Fuel Costs for Option 4

The total fuel costs from Chapter 7 of the Draft RIA comprising the refining and distribution and additive costs for Option 4 are summarized in the following tables.

Table 12.4.3.2.1-1
Total Fuel Costs for Option 4 (cents per gallon)

Option	Specification	Year	Refining Costs (¢/gal)	Distribution & Additive Costs (¢/gal)	Total Costs (¢/gal)
Nonroad, Locomotive and Marine go to 15 ppm in 2010	500 ppm NR, L & M	2007+	2.2	0.3	2.5
	15 ppm NR, L & M (total incl 2007)	2010+	4.6	0.4	5.0

Table 12.4.3.2.1-2
Net Operating Costs for Option 4 Incremental To The Proposal (millions)
(Net present values through 2030 at 3% discount rate)

Specification	Gallons	Fuel costs*	Net maintenance costs	Total operating costs
15 ppm fuel	57,760	$3,100	$20	$1,770
500 ppm fuel	-54,910	-$1,350		

* Note that the incremental fuel costs presented here are calculated as: [proposal $/gal] multiplied by [proposal gallons] minus the [option $/gal] multiplied by [option gallons]. This is not mathematically equivalent to the difference in gallons multiplied by the difference in $/gal.

These fuel costs and other related operating costs (i.e., maintenance savings) result in an increase in the net-present value of Option 4 of approximately $1.8 billion through 2030 as compared to the proposal.

12.4.3.2.2 Engine and Equipment Costs for Option 4

Option 4 has the same engine standards program and implementation dates as the proposal, and therefore the same costs.

12.4.3.3 Option 5a

This option is described in Figure 12.1.2-9 in section 12.1 of this draft RIA. Option 5a has the same fuel program as the proposal but the engine/equipment program differs from the proposal in that no new standards would be implemented for <75 horsepower engines.

12.4.3.3.1 Fuel Costs for Option 5a

Option 5a has no changes on the cost of fuel relative to our proposal. However, the operating costs for <75 horsepower engines are lower than in our proposal due to the elimination of some operating costs for these engines. Specifically, both the PM filter maintenance requirements and our estimate of a two percent fuel consumption increase due to PM filters would be eliminated for all 25 to 75 horsepower engines. Also, CCV maintenance costs would be eliminated for all engines <75 horsepower. Note that oil change maintenance savings would still be realized by these engines as they would be under the proposal. The elimination of these operating costs would result in a decrease in the net-present value of Option 5a of approximately $530 million as compared to the proposal through 2030.

12.4.3.3.2 Engine and Equipment Costs for Option 5a

Engine Fixed Costs

Option 5a would eliminate the need for R&D expenditures described in Chapter 6 as CDPF-only and DOC/engine-out R&D. It would also eliminate the need for tooling expenditures on those engine platforms having sales strictly in the <75 horsepower category. This option would also eliminate proposal-related certification costs for all <75 horsepower engines. Together, these cost reductions would total $140 million relative to the proposal.

Engine Variable Costs

We have removed the variable costs associated with the Tier 4 proposal from the <75 horsepower engines (i.e., DOCs, PM filters, fuel systems, EGR systems, CCV systems) to evaluate the impact of Option 5a on engine variable costs. The NPV of the engine variable costs for Option 5a through 2030 is approximately $3 billion less than the proposal. The annual engine variable costs are shown in Figure 12.4.1.1.2-1.

Equipment Fixed Costs

Option 5a would eliminate any equipment redesign requirements for <75 horsepower equipment. This would reduce the equipment fixed costs of Option 5a by $80 million relative to the proposal.

Equipment Variable Costs

We have eliminated the equipment variable costs for <75 hp equipment for Option 5a. These changes reduce the NPV through 2030 by approximately $70 million relative to the equipment variable costs expected under the proposal.

Total Engine/Equipment Cost

Based on the estimations provided above, we have estimated that Option 5a would result in a decrease in the net-present value of the engine and equipment costs through 2030 of approximately $3.3 billion dollars.

12.4.3.4 Option 5b

This option is described in Figure 12.1.2-10 in section 12.1 of this draft RIA. Option 5b has the same fuel program as the proposal but the engine/equipment program differs from the proposal in that the 2008 standards would remain in effect indefinitely and no CDPF forcing standards would be implemented for 25 to 75 horsepower engines.

12.4.3.4.1 Fuel Costs for Option 5b

Option 5b has no changes on the cost of fuel relative to our proposal. However, the operating costs for <75 horsepower engines are lower than in our proposal due to the elimination of some operating costs for these engines. Specifically, both the PM filter maintenance requirements and our estimate of a two percent fuel consumption increase due to PM filters would be eliminated for all 25 to 75 horsepower engines. Note that, unlike Option 5a, CCV maintenance costs would be incurred for all engines <75 horsepower; also, note that oil change maintenance savings would still be realized by these engines as they would be under the proposal. The elimination of CDPF-related operating costs would result in a decrease in the net-present value of Option 5b of approximately $490 million as compared to the proposal through 2030.

12.4.3.4.2 Engine and Equipment Costs for Option 5b

Engine Fixed Costs

Option 5b would eliminate the need for R&D expenditures described in Chapter 6 as CDPF-only R&D. It would also eliminate the need for CDPF-only tooling expenditures on those engine platforms having sales strictly in the 25 to 75 horsepower category. This option would also eliminate proposal-related certification costs for 25 to 75 horsepower engines beyond 2008. Together, these cost reductions would total $60 million relative to the proposal.

Engine Variable Costs

We have removed the variable costs associated with the 2013 standards of the Tier 4 proposal for 25 to 75 horsepower engines (i.e., PM filters, fuel systems, EGR systems) to evaluate the impact of Option 5b on engine variable costs. The NPV of the engine variable costs for Option 5b through 2030 is approximately $1.9 billion less than the proposal. The annual engine variable costs are shown in Figure 12.4.1.1.2-1.

Equipment Fixed Costs

Option 5b would eliminate any equipment redesign requirements for 25 to 75 horsepower equipment associated with the 2013 standards. This would reduce the equipment fixed costs of Option 5b by $40 million relative to the proposal.

Equipment Variable Costs

For Option 5b, we have eliminated the equipment variable costs for 25 to 75 hp equipment associated with the 2013 standards. These changes reduce the NPV through 2030 by approximately $70 million relative to the equipment variable costs expected under the proposal.

Total Engine/Equipment Cost

Based on the estimations provided above, we have estimated that Option 5b would result in a decrease in the net-present value of the engine and equipment costs through 2030 of approximately $2.1 billion dollars.

12.5 Costs per Ton

For those Program Options where both inventory impacts and cost impacts were generated, it was possible to calculate an incremental cost per ton relative to the proposal. These incremental costs per ton for the Program Options are shown in Table 12.5-1. Note that the cost in Table 12.5-1 are expressed in billions of dollars and the emission reductions in tons of emissions. A brief discussion of how the increment costs per ton were determined is presented below. Note that there is no discussion of cost per ton for Options 1a, 1b, 2a, and 2d, since these Options were determined to be impractical due to infeasibility or other significant concerns, and thus, no costs were calculated.

Table 12.5-1
Incremental Cost per Ton for Alternatives
(Incremental to the Proposal)

Option		NOx+NMHC	PM	SO_2
1	cost ($billion)	-	$1.7	-
	reductions (tons)	11,000	6,000	-191,000
	cost/ton ($/ton)	n/a	$265,000	n/a
2b	cost	-	$1.2	-
	reductions	36,000	54,000	17,000
	cost/ton	n/a	$22,000	n/a
2c	cost	-	$0.8	-
	reductions	16,000	20,000	17,000
	cost/ton	n/a	$41,000	n/a
2e	cost	-$3.1	$12.4[b]	-
	reductions	-5,407,00	1,126,000	-
	cost/ton	$600	$11,000[b]	n/a
3	cost	-$0.2	-$0.2	-
	reductions	-751,000	-30,000	-
	cost/ton	$300	$8,300	n/a
4	cost	-	$0.6	$1.2
	reductions	-	9,000	114,000
	cost/ton	n/a	$64,000	$10,300
5a	cost	-$0.4	-$3.4	-
	reductions	-334,000	-209,000	-
	cost/ton	$1,100	$16,500	n/a
5b	cost	-$0.4	-$2.2	-
	reductions	-333,000	-121,000	-
	cost/ton	$1,100	$18,300	n/a

[a] Qualitative analysis only of options 1a, 1b, 2a, and 2d due to the options being impractical due to infeasibility or other significant concerns.

[b] In the analysis of the proposed program, the cost for 15ppm fuel is split 50/50 between NOx and PM. For option 2e, with no NOx program, all of the 15 ppm fuel cost is attribute to PM resulting in a new cost effectiveness estimate for PM. The PM cost here is the proposal total cost less the proposal SOx cost less the NOx+NMHC savings of Option 2e. For 2e we present the incremental cost effectiveness of the lost NOx tons and the new cost effectiveness of the Tier 4 PM tons.

12.5.1 Incremental Cost per Ton for Option 1

The incremental cost per ton for the lost SO_2 tons due to delaying the introduction of 500 ppm fuel by one year should be roughly the same as the long term SO_2 cost per ton of the 500 ppm fuel program. The cost per ton of SO_2 for that program is $90 (see Table 8.7-1 of this draft RIA). This value is so low because the costs of the 500 ppm fuel program are estimated to be essentially zero due to large maintenance savings expected to occur. In other words, the maintenance savings associated with the 500 ppm sulfur fuel nearly offset the cost of the fuel. See Section 8.4 of this draft RIA for more detail.

The fundamental goal of Option 1 is to introduce new PM controls earlier than the proposal. Therefore, the incremental costs associated with this option – for 15 ppm sulfur fuel two years earlier than the proposal and for PM technology on >75 horsepower engines two years earlier than the proposal – are all attributed to PM. These costs were presented in section 12.4.1.1 as $720 million for fuel and other operating costs and $990 million for engines/equipment for a total of roughly $1.7 billion. The PM tons gained, presented in Table 12.2.3-2, would be 6,000 tons. This results in an incremental cost per ton of PM (i.e., incremental to the proposal) of $265,000.

For NOx+NMHC, the small change in the emission reduction is due to the implementation of the transient test two years early. The feasibility and cost for industry to meet the transient test two years early is not made since this aspect of the option is not a primary consideration in considering this approach. No cost estimate was made for the additional development cost necessary to meet a transient test two years early, so no estimate of the cost per ton of NOx+NMHC is made.

In summary, this alternative gives up virtually free SO_2 reductions to gain very expensive PM tons ($265,000 per ton).

12.5.2 Incremental Cost per Ton for Option 2b

The goal of Option 2b is to introduce new PM controls earlier than the proposal. Therefore, the incremental costs associated with this option – for 15 ppm sulfur fuel one year earlier than the proposal and for PM technology on >25 horsepower engines one year earlier than the proposal – are all attributed to PM. Section 12.4.2.3 discussed the costs of this option as $540 million for fuel and other operating costs and $640 million for engines/equipment for a total of roughly $1.2 billion more than the proposal. Table 12.2.3-2 shows that Option 2b gets 54,000 more tons of PM reduction than does the proposal. This results in an incremental cost per ton of PM of $22,000.

For SO_2 and NOx+NMHC, this option has incidental reductions beyond the proposal due to the sulfur difference between 500 ppm and 15 ppm in 2009 (therefore a larger SO_2 reduction) and the one year early introduction of the transient test procedures (therefore a larger NOx+NMHC reduction). No cost estimate was made for the additional development cost necessary to meet a transient test one year early, so no estimate of the cost per ton of NOx+NMHC is made.

In summary, this alternative gets early PM reductions but has to pay more than double the rate paid under the proposal ($22,000 per ton vs. $9,300 per ton).

12.5.3 Incremental Cost per Ton for Option 2c

The fundamental goal of Option 2c is to introduce new PM controls earlier than the proposal. Therefore, the incremental costs associated with this option – for 15 ppm sulfur fuel one year earlier than the proposal and for PM technology on 175 to 750 horsepower engines one year earlier than the proposal – are all attributed to PM. The costs were presented in section 12.4.2.4 as $530 million for fuel and other operating costs and $300 million for engines/equipment, while Table 12.2.3-2 shows the foregone PM reductions to be 20,000 tons. This results in an incremental cost per ton of PM of $41,000.

This option has incidental SO_2 and NOx+NMHC reductions beyond the proposal due to the sulfur difference between 500 ppm and 15 ppm in 2009 (therefore a larger SO_2 reduction) and the one year early introduction of the transient test procedures (therefore a larger NOx+NMHC reduction). No cost estimate was made for the additional development cost necessary to meet a transient test one year early, so no estimate of the cost per ton of NOx+NMHC is made.

In summary, this alternative gets early PM reductions but has to pay more than three times the rate paid under the proposal ($41,000 per ton vs. $9,300 per ton).

12.5.4 Incremental Cost per Ton for Option 2e

Option 2e reduces compliance costs by eliminating new NOx standards. This option presents legal concerns since we would be giving up achievable NOx emission reductions solely for cost reasons, and cost considerations are not to be the driving factor in making decisions under CAA section 213(a)(3); rather, the overriding goal of this CAA section is air quality (see, for example, Husqvarna AB v. EPA, 254 F. 3d 195, 200 (D.C. Cir. 2001)). Our purpose here, however, is not to address the legality of such a program, but rather to analyze it's merits. Therefore, for the sake of illustration, while the resultant compliance costs would be lower than the proposal, all would be attributed to PM control. The discussion in section 12.4.2.6 noted that the net present value of Option 2e costs would be roughly $3.3 billion dollars less than the proposal ($3.8 billion less for engines/equipment but $460 million more for fuel and other operating costs) while giving up over five million tons of NOx reductions. The cost per ton of these foregone NOx emissions (i.e., dollars saved divided by tons given up) can be estimated at $600 per ton.

For PM and SO_2, there is no change in the reduction realized under this alternative since neither the fuel program nor the new PM standards are different than the proposal. However, if a new cost per ton estimate for the whole program were made for PM, the cost effectiveness would change since the total cost of the 15 ppm sulfur reduction (i.e., sulfur reduction to enable technology) would only be applied to PM. The new cost per ton estimate for PM under this alternative would be $11,000 (as compared to $9,300 under the proposal). Note that this $11,000 cost per ton represents a cost per ton for such a program, not an incremental cost per ton relative to the proposal. For SO_2, there would be no incremental cost per ton since both costs and SO_2 reductions would be equal to the proposal.

In summary, this alternative gives up substantial, feasible NOx reductions at $600 per ton in the same timeframe as our Tier 2 passenger car program (NOx+NMHC cost per ton >$2,000) and the HD 2007 program (>$2,000 per ton). As a PM and SO_2 program, this option is an attractive control option, although PM tons are more expensive than they are under the proposal.

12.5.5 Incremental Cost per Ton for Option 3

This option is basically the same as the proposal except that mining equipment >750 horsepower is exempted from all engine standards. As such, this option roughly estimates the per engine, or equipment, cost per ton for adding or subtracting mining equipment (we do not address here the legal basis, or lack of one, for this option). The cost savings realized for this approach include variable costs for engine hardware, and fixed and variable equipment costs for mining equipment. These savings assume that other nations would also adopt this approach, otherwise no savings would be realized for equipment fixed costs because one product would likely be made worldwide (the engine variable cost savings would still be realized). The savings also include less fuel consumed by these pieces of equipment because without the PM trap they would not incur the one percent fuel economy impact and no PM trap maintenance for these pieces of equipment.

Section 12.4.3.1 presented the incremental costs of this option as $80 million saved on fuel and other operating costs and $410 million saved on engine/equipment costs for a total increment of $490 million saved. However, these savings come at the expense of lower NOx+NMHC and lower PM reductions. Table 12.2.3-2 shows the foregone NOx+NMHC and PM reductions to be 751,000 and 30,000 tons, respectively. Assuming a perfect 50/50 split of costs for these pollutants results in an incremental cost per ton of PM lost of $8,300 an incremental cost per ton of NOx+NMHC lost of $300.

In summary, this alternative gives up substantial feasible and relatively inexpensive (compared to other mobile source programs) NOx+NMHC and PM tons.

12.5.6 Incremental Cost per Ton for Option 4

Option 4 leaves the engine program the same as the proposal but includes locomotive and marine fuel in the requirement for 15 ppm fuel. PM reductions are realized due to the reduced engine out sulfur to sulfate conversion from existing locomotive and marine engines. SO_2

reductions are realized due to the reduced engine out SO_2 from the fuel (98% of the fuel sulfur is exhausted from the engine as SO_2).

The incremental costs for this option were presented in section 12.4.3.2 as $1.8 billion for fuel and other operating costs with no costs for engines/equipment. The PM reductions gained are shown in Table 12.2.3-2 as 9,000 tons and the SO_2 reductions gained are shown as 114,000 tons. To estimate the cost per ton reduction for this alternative, one-third of the incremental 15 ppm fuel cost is attributed to PM with the balance being attributed to SO_2. The resulting incremental cost per ton for PM is $64,000 and the incremental cost per ton of SO_2 is $10,300.

In the absence of new engine standards enabled by the 15 ppm sulfur fuel (i.e., for locomotive and marine engines), the cost per ton of emissions reduction for this option does not look as favorable as some of the other options listed here. However, we would anticipate that a fuel program such as this would be done in conjunction with new technology forcing emission standards enabled by this clean fuel. In fact, as discussed in Section 6.C of the preamble, it is our intention to develop an Advanced Notice of Proposed Rulemaking (ANPRM) for such a control option in the near future. Were this option to include new the control technology enabled by 15 ppm sulfur fuel, we believe it is likely that the program would look very favorable. The cost per ton estimates for Option 3 would likely be a good surrogate for an estimation of such a program for locomotive and marine engines (i.e., the program would be very cost effective compared to other PM emission control programs).

12.5.7 Incremental Cost per Ton for Option 5a

This option is similar to the proposal except that no new standards would be implemented for <75 horsepower engines. In other words, engines <50 horsepower would remain at Tier 2 levels and 50 to 75 horsepower engines would remain at Tier 3 levels. As such, this option roughly estimates the per vehicle cost per ton for adding or subtracting the <75 horsepower elements of the engine program. The cost savings realized for this approach include variable costs for engine hardware and equipment hardware in the <75 horsepower category, and fixed costs for engine R&D, tooling, and certification, and equipment redesign in the <75 horsepower category. These savings assume that other nations would also adopt this approach, otherwise no savings would be realized for equipment fixed costs because one product would likely be made worldwide (the engine variable cost savings would still be realized). The savings also include less fuel consumed by 25 to 75 horsepower pieces of equipment because without the PM trap they would not incur the two percent fuel economy impact associated with the PM trap. Further, 25 to 75 horsepower pieces of equipment would not incur the PM trap related maintenance costs and all engines <75 horsepower would not incur the CCV maintenance costs because CCV systems would not be required.

Section 12.4.3.3 presented the incremental costs of this option as $530 million saved on fuel and other operating costs (i.e., lower operating costs) and $3.3 billion saved on engine/equipment costs for a total increment of $3.8 billion saved. However, these savings come at the expense of lower NOx+NMHC and lower PM reductions. Table 12.2.3-2 shows the foregone NOx+NMHC and PM reductions to be 334,000 and 209,000 tons, respectively. Attributing these costs to NOx+NMHC and PM according to the cost allocations shown in Table 8.1-2 results in an incremental cost per ton of PM lost of $16,500 and an incremental cost per ton of NOx+NMHC lost of $1,100.

In summary, this alternative gives up substantial feasible (compared to other mobile source programs) NOx+NMHC and PM tons.

12.5.8 Incremental Cost per Ton for Option 5b

This option is similar to the proposal except that the 2008 standards for <75 horsepower engines would remain in effect indefinitely and no new PM trap forcing standards would be implemented for 25 to 75 horsepower engines nor new EGR forcing NOx standards for 25 to 50 horsepower engines. As such, this option roughly estimates the per engine, or equipment, cost per ton for adding or subtracting the 2013 standards for 25 to 75 horsepower engines (we do not address here the legal basis, or lack of one, for this option). The cost savings realized for this approach include variable costs for engine hardware and equipment hardware associated with the 2013 standards, and fixed costs for engine R&D, tooling, and certification, and equipment redesign associated with the 2013 standards. These savings assume that other nations would also adopt this approach, otherwise no savings would be realized for equipment fixed costs because one product would likely be made worldwide (the engine variable cost savings would still be realized). The savings also include less fuel consumed by 25 to 75 horsepower pieces of equipment because without the PM trap they would not incur the two percent fuel economy impact associated with the PM trap. Further, 25 to 75 horsepower pieces of equipment would not incur the PM trap related maintenance costs.

Section 12.4.3.4 presented the incremental costs of this option as $490 million saved on fuel and other operating costs (i.e., lower operating costs) and $2.1 billion saved on engine/equipment costs for a total increment of $2.6 billion saved. However, these savings come at the expense of lower NOx+NMHC and lower PM reductions. Table 12.2.3-2 shows the foregone NOx+NMHC and PM reductions to be 333,000 and 121,000 tons, respectively. The foregone NOx+NMHC reduction relative to the proposal is almost identical for Option 5b as it was for Option 5a although it is slightly lower due to the NMHC reduction realized by the addition of DOCs under Option 5b that would not be realized under Option 5a. Attributing these costs to NOx+NMHC and PM according to the cost allocations shown in Table 8.1-2 results in an incremental cost per ton of PM lost of $18,300 an incremental cost per ton of NOx+NMHC lost of $1,100.

In summary, this alternative gives up substantial feasible (compared to other mobile source programs) NOx+NMHC and PM tons.

12.6 Summary and Assessment of Alternative Program Options

Having presented each of the alternative Program Options and their associated inventory impacts, benefits, costs, and cost-effectiveness in the preceding sections, we here provide a comparative summary of these Options and an assessment of the rationale, issues, and feasibility of each one.

12.6.1 Summary of Results of Options Analysis

As we developed the program we are proposing in today's Notice of Proposed Rulemaking, we evaluated a number of alternative Program Options with regard to the scope, level, and timing of the standards to ensure that we were looking at the full range of possible control options. Table 12.6.1-1 contains a summary of the alternative Program Options we considered and the expected emission reductions, costs, and monetized benefits associated with them in comparison to the proposal. These Program Options cover a broad range of possible approaches and serve to provide insight into the many other program design alternatives not expressly evaluated further.

While we are interested in comments on all of the alternatives presented, we are especially interested in comments on two alternative scenarios that we believe merit further consideration in developing the final rule; a primary one-step program (Option 1), and a requirement that the second step of sulfur control to 15 ppm in 2010 apply to locomotive and marine diesel fuel in addition to nonroad diesel fuel (Option 4).

Table 12.6.1-1
Summary of Alternative Program Options
(Incremental to the Proposal)

Option	Fuel Standards	Engine Standards	Estimated Relative Inventory Impacts[c] (NPV tons thru 2030; 3% discount)	Estimated Cost Impacts - $Billion (NPV thru 2030; 3%)	Estimated Benefits Stream - $Billion[e] (NPV thru 2030; 3%)
Proposal ***(inventory impacts, costs and benefits reported below for the options are compared to the proposal)***					
	• 500 PPM in 2007 for NR, loco/marine • 15 ppm in 2010 NR only	• >25 hp: PM AT introduced 2013 • >75 hp: NOx AT introduced and phased-in 2011-2013 • <25 hp: PM stds in 2008 • 25-75 hp: PM stds in 2008 (optional for 50-75 hp)	Relative to baseline: 1,126,000 PM 4,952,000 SO2 5,591,000 NOx+NMHC	$16.7	$550[b]
1-Step Fuel Options					
1	• 15 ppm in 2008 for NR only • 500 ppm in 2008 for loco/marine	• < 50 hp: PM stds only in 2009 • 25-75 hp: PM AT stds and EGR or equivalent NOx technology in 2013; no NOx AT • >75 hp: PM AT stds phasing in beginning in 2009; NOx AT phasing in beginning in 2011	6,000 PM -191,000 SO2 11,000 NOx+NMHC	$1.7[d]	$.2[b]
1a	• 15 ppm in 2008 for NR, loco/marine	• PM AT introduced in 2009-10 • NOx AT introduced in 2011-12	129,000 PM -63,000 SO2 1,843,000 NOx+NMHC	a	$59
1b	• 15 ppm in 2006 for NR, loco/marine	Same as 1a	a		
2-Step Fuel Options					
2a	Same as proposal except – • 500 ppm in 2006 for NR, loco/marine	Same as proposal	18,000 PM 228,000 SO2 0 NOx+NMHC	a	$7[b]
2b	Same as proposal except – • 15 ppm in 2009 for NR	Same as proposal except – • Move PM AT up 1 year for all engines > 25 hp (phase in starts 2010)	54,000 PM 17,000 SO2 36,000 NOx+NMHC	$1.2[d]	$16[b]
2c	Same as proposal except – • 15 ppm in 2009 for NR	Same as proposal except – • Move PM AT up 1 year for all engines 175-750 hp (phase in starts 2010)	20,000 PM 17,000 SO2 16,000 NOx+NMHC	$0.8[d]	$6[b]

Option	Fuel Standards	Engine Standards	Estimated Relative Inventory Impacts[c] (NPV tons thru 2030; 3% discount)	Estimated Cost Impacts - $Billion (NPV thru 2030; 3%)	Estimated Benefits Stream - $Billion[e] (NPV thru 2030; 3%)
2d	• Same as proposal	Same as proposal except – • Phase-in NOx AT for 25-75hp beginning in 2013	0 PM 0 SO2 751,000 NOx+NMHC	a	$10[b]
Other Options					
3	• Same as proposal	Same as proposal except – • Mining equipment over 750 hp left at Tier 2	-30,000 PM 0 SO2 -751,000 NOx+NMHC	-$0.5	-$18[b]
4	Same as proposal except – • loco/marine fuel to 15 ppm in 2010	Same as proposal	9,000 PM 114,000 SO2 0 NOx+NMHC	$1.8	$6[b]
5a	• Same as proposal	Same as proposal except- • No Tier 4 standards <75 hp	-209,000 PM 0 SO2 -334,000 NOx+NMHC	-$3.8	-$70
5b	• Same as proposal	Same as proposal except- • No new <75hp standards after 2008 (i.e., no CDPFs in 2013)	-121,000 PM 0 SO2 -333,000 NOx+NMHC	-$2.6	-$43

[a] Qualitative analysis only. Option is impractical due to infeasibility or other significant concerns. See the draft RIA for a detailed discussion

[b] By benefits transfer method

[c] Net Present (2004) Value impacts through 2030, using a 3% discount rate, relative to the proposed program. Positive values mean that the Option produces greater emission reductions from baseline than the proposed program.

[d] Cost estimates do not include the costs due to potential for limited product offerings and market disruptions in the engine/equipment and/or fuel markets. See Section V of this preamble and the draft FIA for a detailed discussion.

[e] Benefits do not include CO, VOC, air toxics, ozone, and PM welfare benefits. See Section V.F of this preamble and the draft RIA for additional discussion.

12.6.2 Discussion of Rationale, Issues, and Feasibility Assessment of Options

Each of the Program Options defined and presented in Section 12.1 is discussed here in terms of the rationale for considering the option, issues surrounding the option, and our assessment of the feasibility of the option. Inventory impacts for each option are presented in Section 12.2, health and environmental benefit comparisons are presented in Section 12.3, and comparative cost and cost-effectiveness for these Program Options is presented in Sections 12.4 and 12.5, respectively.

12.6.2.1 One-Step Options

12.6.2.1.1 Option 1

In defining Option 1 we focused on designing a program with long-term engine standard levels identical to those being proposed, implemented as early as possible under a one-step approach to nonroad fuel desulfurization, and structured such that both engine and fuel requirements and timing would have a high likelihood of being technologically feasible. In doing so, we recognized the need to account for a number of factors:

- The need for 15 ppm maximum sulfur nonroad diesel fuel to enable highly-sulfur sensitive emission control technology on nonroad engines,
- The need to coordinate refinery investments to desulfurize nonroad diesel fuel with similar efforts already mandated for this industry for highway diesel fuel and gasoline in the same general timeframe,
- The need to provide adequate lead time for the migration of relevant emission control technologies from the highway sector,
- The need to provide adequate stability periods for Tier 3 standards and for Tier 2 standards for engines under 50 hp, and
- The workload of engine and equipment manufacturers in preparing hundreds of engine models and thousands of machine models for Tier 4 compliance.

The resulting Option 1 program design is reflected in Figure 12.1.1-1. The one-step fuel change occurs in 2008. This is one year later than the proposal’s first step, but it provides 15 ppm maximum sulfur nonroad diesel fuel two years earlier than the proposal’s second step does. In Option 1, locomotive and marine diesel fuel is desulfurized to 500 ppm in 2008 as well, one year later than under the proposal.

These fuel program differences yield both positive and negative impacts on relative emissions reductions. Early sulfate PM reductions in the existing fleet would be delayed a year such that no PM reductions would occur in 2007. The Tier 4 PM standard for <25 hp engines and the transitional PM standard for 25-50 hp engines would both be delayed a year to 2009, and the transitional PM standard for 50-75 hp engines would be eliminated. These differences come about because these PM standards depend on the availability of nonroad diesel fuel with sulfur levels below 500 ppm, which under the one-step fuel option does not happen until the shift to 15 ppm fuel in 2008. This delays any potential PM standards to 2009 at earliest and, in the case of 50-75 hp engines which have new Tier 3 standards taking effect in 2008, makes it unworkable to adopt the transitional standard at all because these engines (and the machines using them) would need to be redesigned for new emission standards in 2008, again in 2009, and yet again in 2013, as discussed below. Even we were to have the transitional standard take effect in 2010 or 2011 instead of 2009 in order to pace the redesign process more evenly, these rapid redesigns would likely be unacceptably costly.

The most important impact of this Option 1 fuel regulation schedule is the potential for high-efficiency exhaust emission control to occur as early as the 2009 model year. Even accounting for the other factors listed above, such as the need to provide adequate lead time for the migration of relevant emission control technologies from the highway sector, PM filters can be introduced earlier on a large segment of nonroad diesel engines under Option 1. Our consideration of these factors in setting a NOx standard schedule, particularly the need for technology migration lead time, leads us to conclude, however, that the earlier availability of 15 ppm sulfur fuel would not lead to earlier implementation of NOx adsorber technology. The completion of the NOx technology phase-in for the highway sector will occur in 2010. We believe that 2011 would remain as the earliest model year that this technology could begin to phase into the nonroad diesel sector, as proposed.

Although earlier introduction of PM filter technology is made possible by the earlier availability of enabling fuel, the need for adequate lead time to transfer PM filter technology from the highway sector to the wide variety of nonroad diesel applications, and the need for a coordinated PM/NOx phase-in to avoid large and costly redesign workload burdens, result in a somewhat complex phase-in schedule for Option 1. (For analysis of an option that does not take much account of this constraint, see section 12.6.2.1.2 on Option 1a below.) Specifically, we would phase in standards as indicated in Figure 12.1.1-1. Engines in the 175-750 hp category would be subject to the 0.01 g/bhp-hr PM filter-based standard in 2009, when the regulated fuel becomes available, but only for 50% of a manufacturer’s U.S.-directed production. The other 50% would meet this PM standard beginning in 2011, concurrent with initiation of the 0.30 g/bhp-hr NOx adsorber-based standard for 50% of production. This makes it possible to optimize the PM filter technology transfer process by focusing on the most “highway-like” engine platforms in this power category first, and also to reduce the engineering workload by redesigning many engine families, comprising half of production, to meet PM and NOx standards simultaneously in the 2011 model year. The NOx phase-in would then be completed in 2014, as under the proposal, allowing five years of stability for the 50% of production redesigned for PM control in 2009 before the redesign for NOx in 2014. All in all, this approach increases the opportunity for a manufacturer to coordinate product redesign strategies for new standards with product redesign cycles driven by marketing and other concerns, while still achieving substantial PM filter introduction in 2009.

The phase-in for engines in the 75-175 hp category would follow the same pattern, but one year later, to account for the need to spread the workload, and also to provide additional time to transfer highway technology to engines in this category, as is done under the proposal and in past tiers of standards. Note that this approach to phasing in standards helps to optimize the redesign strategies to reduce workload burden, but not as well as under the proposal. It also does not fully mitigate concerns over shortened Tier 3 stability periods under Option 1, reduced to two years for some engines (50% of 75-100 hp engines).

For engines over 750 hp, we have retained the proposal's 50% phase-in approach in 2011-2013. We believe that decoupling the PM and NOx phase-in for this category by implementing the PM standard one or two years earlier could potentially create severe problems. These engines typically are used in low sales volume machines that have long normal product cycles. Early PM control would not only result in two Tier 4 redesigns steps for some of these engines and machines, but would also shorten the Tier 2 stability period.

The implementation issue is somewhat simpler for engines below 75 hp because of the lack of NOx-adsorber based standards. For the engines below 25 hp it is simplified even further by the lack of PM filter-based standards. These would be subject to a non-PM filter-based standard in 2009, when the regulated fuel becomes available. (See Section 4.1.1 for a discussion of how fuel sulfur degrades the efficiency of diesel oxidation catalysts used for PM control.) We believe that PM filter technology for 25-75 hp engines is constrained primarily by highway technology transfer considerations, and thus would be implemented in Option 1 in 2013 as under the proposal. This is late enough that it would still make sense under Option 1 to adopt transitional PM standards as in the proposal, even with the one-year delay to 2009 caused by the delay in fuel regulation. However, transitional standards would not be applied under this option to the 50-75 hp engines in this category because of the conflict with Tier 3 timing discussed above.

12.6.2.1.2 Option 1a

The analysis for Option 1a shows what added environmental benefits would be possible under a very aggressive approach to engine standard-setting, compared to the proposal and to the more technologically feasible Option 1. On the fuel side, Option 1a would go further than the proposal and Option 1 by regulating locomotive and marine diesel fuel to the 15 ppm maximum sulfur level along with other nonroad diesel fuel in 2008. Issues associated with regulating locomotive and marine fuel to 15 ppm sulfur are discussed in section 12.6.2.2.8. Otherwise the approach to fuel regulation is identical to that taken in Option 1.

The Option 1a approach to engine standards applies the 0.01 g/bhp-hr PM standard to engines of all sizes: in 2009 for engines >175 hp and in 2010 for engines <175 hp. This is 2-5 years earlier than under the proposal for engines above 75 hp. For 25-75 hp engines, it is three years earlier and at a 50% lower emission level (0.01 compared to 0.02 g/bhp-hr), but without the proposed 2008 transitional PM standard that is tied to regulating fuel in two steps. For engines

<25 hp, the Option 1a approach to PM standard-setting is two years later than the proposed Tier 4 standard but at a PM filter-based level 97% lower than the proposed 0.30 g/hp-hr level. Although Option 1a's two-year phase-in of the PM standard in 2009-2010 follows the logic that fuel desulfurization must precede the application of PM filters, and directionally addresses the critical workload and technology transfer issues detailed in section III of the proposal, we do not believe that this analytical option is technologically feasible with respect to PM standard-setting, for reasons discussed in Chapter 4 and in section III of the preamble to the proposal.

For NOx control, Option 1a applies a similar 2-year phase-in: in 2011 for engines >175 hp and in 2012 for engines <175 hp. These later NOx start dates compared to those of the Option 1a PM standards directionally reflect the need for additional development time after similar standards fully phase in for heavy-duty highway diesel engines in 2010, in order to transfer this technology to nonroad applications. This phase-in of NOx standards results in an Option 1a Tier 4 program with NOx adsorber-based standards fully phased in three years earlier than under the proposal for engines >175 hp, and two years earlier than under the proposal for 75-175 hp engines, although for all of these engines >75 hp, the proposal begins phasing in the NOx standard (at a 50% of sales level) in the same year that Option 1a begins its NOx control requirement (at 100%). For engines <75 hp, Option 1a's 0.30 g/bhp-hr NOx standard would yield over 90% better NOx control than the non-NOx adsorber-based standards under the proposal. As concluded above for PM control, however, we do not believe that this analytical option is technologically feasible with respect to NOx standards-setting, for reasons discussed in Chapter 4 and in section III of the preamble to the proposal.

One additional major complication created by Option 1a's focus on getting PM control as early as possible is the very large additional workload, especially for equipment manufacturers, created by having two major Tier 4 redesign steps coming two years apart for every engine, first for PM in 2009-2010, and then for NOx in 2011-2012. Moreover, these major redesigns follow quite closely on the major engine and equipment redesign effort in 2006-2008 for Tier 3 (and Tier 2 for engines >750 hp), with Tier 3 stability periods as short as 2 years for many engines. Stability periods this short would be unprecedented in EPA mobile source programs for technology-forcing standards such as those required by Tier 3 and the proposed Tier 4. Furthermore, the Option 1a approach would result in an overlap of implementation schedules for nonroad Tier 4 standards and the highway HDDE emission control program that phases in over 2007-2010. A number of engine manufacturers participate in both markets, and thus would likely be certifying and marketing new highway engines in 2009 and 2010, concurrent with the turnover of their entire nonroad engine product line to meet the new nonroad diesel PM standard in the same years. This could put a serious strain on their engineering resources and add to the cost of the program, potentially to the extent of making the program infeasible.

Based on the above discussion and the analyses performed for this option described in this Chapter, we conclude that Option 1a would not be appropriate for proposal. In particular, we do not believe that the set of engine standards under Option 1a would be technologically feasible.

12.6.2.1.3 Option 1b

This alternative, a variation of Option 1a, would implement a 15 ppm sulfur cap for all nonroad, locomotive, and marine diesel fuel starting on June 1, 2006 for refiners and importers. The rationale behind doing so would be to move up the program for NRLM fuel to coincide with the initial implementation of the 15 ppm cap for highway diesel fuel. The engine standards would be unchanged in comparison to Option 1a. They would still be initiated starting with the 2009 model year for PM and 2011 model year for NOx. Thus, this alternative, relative to Option 1a, would be a pure fuel program, moving up the 15 ppm sulfur standard by two years.

We have examined this alternative from a number of angles relative to the proposal and Option 1a:
1) The need for further sulfur dioxide and PM emission reductions in this timeframe,
2) Its impact on the desulfurization technology used to meet the 15 and 500 ppm caps,
3) The leadtime available for refiners to meet the 15 and 500 ppm standards in 2006,
4) The impact on the supply of highway diesel fuel, and
5) The potential cost-effectiveness and cost-benefit of the additional sulfur control.

Because this option only affects fuel sulfur content and not engine emission standards, the only air quality benefits are reduced sulfur dioxide and sulfate PM emissions. The need for these reductions is just as great in 2006-7 as they are in the 2008-2010 timeframe. As outlined in Chapter 2, ambient fine PM levels are currently above the NAAQS for fine PM. Ambient fine PM levels in 2006-2007 are more likely to be near current levels than those in 2008-2010, given that less time is available for current emission controls, like the 2007 highway diesel program, to take effect. Thus, moving up the 15 ppm standard should be considered for its air quality impacts. These emission reductions and their resulting benefits are shown in Sections 12.2.2 and 12.3, respectively.

However, a 2006 implementation date for a 15 ppm sulfur cap on all NRLM fuel does not appear to allow sufficient leadtime for refiners to design and construct new desulfurization equipment. Leadtime for the proposed 2007 500 ppm NRLM diesel fuel cap was evaluated in Chapter 5.3. There it was determined that refiners needed 2.25-3.25 years after the final rule in order to design and construct new hydrotreaters to produce 500 ppm fuel. This analysis considered the fact that the 500 ppm cap could be met using well established, conventional hydrotreating technology. More time would be required to design and construct equipment to produce 15 ppm nonroad diesel fuel. Even ignoring this additional time, a 2006 implementation date would only allow refiners facing the minimum required leadtime enough time to meet the one-step fuel standards. A 2006 implementation date would allow no time for the generation of early sulfur reduction credits which might allow some refiners additional time to meet the one-step fuel standards. Also, it is difficult to project that any refiners would be able to meet these standards early even if the program granted such credits. Thus, we must conclude that the 2006 one-step option would not be technically feasible due to insufficient leadtime for refiners and importers to meet the 2006 fuel sulfur standards. For this reason, we were unable to develop any reliable cost estimates for this option.

In addition to leadtime concerns, applying a 15 ppm sulfur cap for NRLM diesel fuel in 2006 to coincide with the implementation of the highway diesel fuel program would raise workload concerns for the industry, impacting not only the successful implementation of this rulemaking, but also the highway rule. A 15 ppm cap on NRLM fuel in 2006 could have seriously adverse consequences on the supply of highway diesel fuel and thus, the successful implementation of the 2007 highway diesel fuel program. We added the temporary compliance option to the 2007 highway diesel fuel program to ease implementation in 2006 and assure sufficient supply of highway diesel fuel. The temporary compliance option allows 20% of highway diesel fuel to remain at 500 ppm until 2010. Starting a 15 ppm NRLM cap in 2006 would essentially negate the benefit of the temporary compliance option, as the volume of high sulfur nonroad diesel fuel is roughly 15% of highway diesel fuel volume. We have not evaluated the degree that highway fuel supply would be negatively impacted, however, the impact would be directionally negative.

Since this option is not feasible, we were not able to derive costs, and therefore cost per ton or cost/benefit values that correspond to it. However, under the hypothetical where leadtime was not a constraint on feasibility, we can still provide some general assessments. Applying a 15 ppm cap in 2006 for all NRLM fuel would reduce refiners' ability to utilize lower cost, advanced desulfurization technologies to meet the 15 ppm nonroad diesel fuel sulfur cap. This is discussed in Chapters 5 and 7 above. In 2006, we would project that few if any refiners would utilize advanced technologies. This would increase the cost of 15 ppm fuel by roughly 10% compared to Option 1 where 40% of refiners are estimated to be able to take advantage of these technologies and more than 20% in comparison to today's proposal. This impact on cost would last for roughly 15 years, or as long as this equipment was in use. Other than this increase in costs, the incremental cost effectiveness and cost-benefit ratio would be expected to be of a similar magnitude to that for option 4 as discussed in chapter 12.6.2.2.8 below. Thus, a rough estimate suggests that if this option were feasible, the benefits would still be substantial and costs would be reasonable, but not nearly as well as is true for the proposal or a long term 500 ppm cap.

12.6.2.2 Two-Step Options

12.6.2.2.1 Proposed Program

The proposed program is included in this Chapter for the purpose of comparison with the alternative regulatory options analyzed. We believe it to be a feasible program that meets the Agency's requirements under the Clean Air Act. The proposed program is described in detail in the preamble to the proposal and the feasibility of the proposed engine and fuel requirements is discussed in detail in Chapters 4 and 5 of the draft RIA.

12.6.2.2.2 Option 2a

This alternative would move up the 500 ppm sulfur cap for NRLM diesel fuel one year, to June 1, 2006 for refiners and importers. The rationale behind doing so would be to move up the 500 ppm cap for NRLM diesel fuel to coincide with the initial implementation of the 15 ppm cap for highway diesel fuel. The aftertreatment-based engine PM emission standards would not be moved up. They would still be initiated starting with the 2011 model year. Thus, this alternative, relative to the proposal, would be a pure fuel program, moving up the 500 ppm fuel controls of the proposal by one year.

We have examined this alternative from a number of angles relative to the proposal:

1) The need for further sulfur dioxide and PM emission reductions in this timeframe,
2) Its impact on the desulfurization technology used to meet the 15 and 500 ppm caps,
3) The leadtime available for refiners to meet the 15 and 500 ppm standards in 2006,
4) The impact on the supply of highway diesel fuel, and
5) The potential cost-effectiveness and cost-benefit of the additional sulfur control.

Because this option only affects fuel sulfur content and not engine emission standards, the only air quality benefits are reductions of sulfur dioxide and sulfate PM emissions. The need for these reductions should be just as great in 2006 as they are in the 2007-2010 timeframe. As outlined in Chapter 2, ambient fine PM levels are currently above the NAAQS for fine PM in many areas of the country. Ambient fine PM levels in 2006 are more likely to be near current levels than those in 2007-2010, given that less time is available for current emission controls, like the 2007 highway diesel program, to take effect. Thus, moving up the 500 ppm cap should be considered for its direct air quality impacts. These emission reductions and their resulting health and welfare benefits are shown in Section 12.2 and 12.3, respectively.

Applying the 500 ppm cap in 2006 as opposed to 2007 should have little impact on the refining technology used. In Chapter 5, we project that conventional hydrotreating technology which has been used for over 10 years to produce 500 ppm diesel fuel would be used by refiners to meet a 500 ppm cap in 2007. This would also be the case for a 2006 standard, if refiners had sufficient time to build new equipment.

However, a 2006 implementation date for the 500 ppm NRLM sulfur cap does not appear to allow sufficient leadtime for refiners to design and construct new desulfurization equipment. Leadtime for the proposed 2007 500 ppm NRLM diesel fuel cap was evaluated in Chapter 5.3. There it was determined that refiners needed 2.25-3.25 years after the final rule in order to design and construct new hydrotreaters to produce 500 ppm fuel. A 2006 implementation date would only allow refiners facing the minimum required leadtime enough time to comply. A 2006 implementation date would allow no time for the generation of early sulfur reduction credits which might allow some refiners additional time to meet the two-step fuel standards. Also, it is difficult to project that any refiners would be able to meet these standards early even if the program granted such credits. Thus, we must conclude that the 2006 two-step option would not be technically feasible due to insufficient leadtime for refiners and importers to meet the 2006 fuel sulfur standards. For this reason, we were unable to develop any reliable cost estimates for this option.

In addition to leadtime concerns, as with Option 1b, moving up the 500 ppm standard to coincide with the implementation of the highway diesel fuel program would also raise workload concerns for the industry impacting not only the successful implementation of this rulemaking, but also the highway rule. A 500 ppm standard in 2006 could have an adverse impact on the supply of highway diesel fuel and thus, the successful implementation of the 2007 highway diesel fuel program. We added the temporary compliance option to the 2007 highway diesel fuel program to ease implementation in 2006 and assure sufficient supply of highway diesel fuel. The temporary compliance option allows 20% of highway diesel fuel to remain at 500 ppm until 2010. Starting the 500 ppm NRLM cap in 2006 would increase the strain on the design and construction industries, as not only the 2007 highway diesel fuel program, but also the Tier 2 gasoline program are being implemented in the same timeframe. It would also increase the amount of capital which would need to be raised by the refining industry. We have not evaluated the degree that highway fuel supply would be negatively impacted. However, the impact would be directionally negative.

Since this option is not feasible, we were not able to derive costs, and therefore cost per ton or cost/benefit values that correspond to it. However, were more time given prior to implementation of the 500 ppm cap, such that leadtime was no longer a constraint on feasibility, the option essentially turns into the proposed requirement for 500 ppm beginning June 1, 2007 (with its associated costs, emission reductions, and benefits).

12.6.2.2.3 Option 2b

Compared to the proposal, Option 2b pulls the 15 ppm maximum sulfur fuel requirement forward by one year to 2009. It also pulls all of the PM filter-based PM standards forward by one year to take advantage of the earlier fuel availability.

Moving up the 15 ppm standard for nonroad diesel fuel by one year would increase refining costs two ways. One, it would increase the cost of nonroad diesel fuel produced between June 1, 2009 and June 1, 2010 by 2.4 cents per gallon (from the 2.2 cent per gallon cost of 500 ppm nonroad diesel fuel to the 4.6 cent per gallon cost of 15 ppm nonroad diesel fuel in 2009). (See Table 12.4.2.3.1-1 above.) Two, it would increase the cost of nonroad diesel fuel produced after June 1, 2010 by 0.2 cents per gallon, as the cost of producing 15 ppm nonroad diesel fuel would be 4.4 cents per gallon for the proposed implementation date of June 1, 2010.

Moving up the 15 ppm standard for nonroad diesel fuel by one year would also make the nonroad diesel fuel sulfur program more stringent than the highway diesel fuel sulfur program, which does not require 100% of highway diesel fuel to meet a 15 ppm cap until June 1, 2010.

Some of the synergies obtained by the proposed program would also be lost. Roughly 20 refineries are projected to start producing both 15 ppm highway diesel fuel and 15 ppm nonroad diesel fuel in 2010. Requiring the production of 15 ppm nonroad diesel fuel at the same time that the last 20% of highway diesel fuel must meet this standard would allow these two projects to be fully coordinated, if not become a single project. Also, the three year interval between the proposed 500 ppm and 15 ppm caps for nonroad diesel fuel is roughly equal to the life of a desulfurization catalyst. Thus, many refiners would be bringing their 500 ppm desulfurization unit down for catalyst replacement right about the time that the additional equipment needed to meet the 15 ppm cap would need to be tied in. Implementing the 15 ppm cap one year earlier would require refiners to either replace their existing catalyst earlier than necessary or bring the unit down the next year again for another catalyst replacement.

In addition, Option 2b would involve a number of engine program considerations beyond those analyzed for the proposed program. The primary effect of the pull-forward of PM control is, of course, one-year earlier PM reductions. Over the very long-term the emissions impacts of phase-in schedule differences diminish to zero, but during the phase-in years and shortly thereafter, the differences can be substantial, given the over 90% PM reduction achieved by each new engine entering the fleet meeting the proposed Tier 4 standard. Section 12.2 analyses these impacts in detail.

The one-year pull-forward of PM standards would decouple PM and NOx control for many engines. Engines <25 hp would be unaffected because there are no PM filter-based standards for them. However, 25-50 hp engines would require redesign for PM control in 2012 and redesign for NOx control in 2013. This could create substantial increases in engineering workload for both engine and equipment manufacturers attempting to carry out the double redesign for two consecutive model years. This increase might conceivably be mitigated somewhat by coordinated advance planning, such as by engine manufacturers anticipating NOx-based changes to their engines and exhaust systems (NOx/PM exhaust emission control device canning dimensions, for example), and providing these specifications to their equipment manufacturer customers a year before those changes are actually made to allow for a single machine redesign effort. Given the large impacts that even modest standards changes have had on equipment designs in Tier 2, and the difficulty some engine manufacturers have had in providing their customers with design specifications and prototypes very far ahead of time, it is not clear that such pre-planning would be very effective.

Like engines <25 hp, engines in the 50-75 hp range would not experience a PM/NOx standard decoupling under Option 2b because we are not proposing to change the NOx+NMHC standard from the 2008 Tier 3 standard level for these engines. Engines above 75 hp would experience this decoupling, however. For 75-175 hp engines, PM filters would be applied in 2011, and NOx adsorbers would begin to phase in in 2012. For 175-750 hp engines, PM filters would be applied in 2010, and NOx adsorbers would begin to phase in in 2011. For engines >750 hp, PM filters would be applied to 50% of engines in 2010. In 2011 and 2012, a recoupled NOx/PM redesign strategy could be pursued with 50% of engines requiring both NOx and PM

Tier 4 controls. However, the standards would then be decoupled again as the remaining 50% of engines are fitted with PM filters in 2013, and then NOx adsorbers in 2014. As for 25-50 hp engines, some comprehensive pre-planning could help mitigate the costs of decoupling, but past experience makes it doubtful that much of this could be assumed. All in all, Option 2b is likely to result in a large increase in engineering workload for engine and equipment manufacturers.

In addition, earlier long-term PM standards would shorten the stability periods for previous standards accordingly. The 0.22 g/bhp-hr transitional PM standard for 25-75 hp engines would be in effect for only four model years, 2008-2011, instead of five. Likewise, previous-tier standards for >75 hp engines would be in effect for three or four years, depending on engine size. These shortened stability periods may not directly impact the feasibility of standards, but would certainly have an adverse impact on manufacturers' ability to accomplish all required redesigns without increasing engineering staffs and would also reduce the number of years available to recover fixed costs.

We have not done a detailed analysis of the technological feasibility of PM filter application one year earlier than under the proposal. The earliest Option 2b application date, 2010 for engines above 175 hp, is three years after similar technologies will be required for HDDEs. Although we believe that this is likely to provide adequate lead time to accomplish the transfer of this technology to some nonroad diesel applications, it is not clear that this could be accomplished for 100% of the 175-750 hp nonroad engines and 50% of the >750 hp engines by 2010, and for all other nonroad diesel engines above 25 hp shortly after this. Even with engine platforms on which this accelerated schedule could be accomplished, we would anticipate costs to rise due to the shortened opportunity for learning from highway experience and the resulting need for basic R&D to develop PM control technology directly in the nonroad sector.

Finally, we expect that under Option 2b, the technology review for engines under 75 hp, discussed in section III.G of the proposal, would need to occur in 2006 rather than 2007, to allow adequate lead time should program adjustments be deemed appropriate. Given the large experience base expected to accumulate during 2007 as highway engines equipped with advanced PM and NOx emissions controls take to the road in large numbers, the one-year earlier review schedule would be unfortunate.

Based on the above discussion and the analyses performed for this option described in this Chapter, we conclude that Option 2b would not be appropriate for proposal. In particular we see the large increase in engine and equipment manufacturers' workload for redesign, the shortened stability periods for previous-tier standards, and the need for additional R&D expenditures for some degree of parallel nonroad/highway emission control development work, as large potential barriers to implementing this option.

12.6.2.2.4 Option 2c

Option 2c is very similar to Option 2b except that PM filter-based standards would be pulled forward by one year only for 175-750 hp engines. All points of the above discussion on Option 2b are relevant here except of course that discussion points specific to <175 hp and >750 hp engines would not apply. Engines in the 175-750 hp category comprise a large segment of the emissions inventory, of the engine families, and of the total U.S. nonroad engine sales. As a result the environmental impact of Option 2c, though not as large as that of Option 2b, is substantial compared to the proposed program, especially in the early years of Tier 4. Likewise, the adverse impacts of the Option 2c PM pull-forward on the engine and equipment manufacturing industries would be large, though more focused on those manufacturers with products in this power range. This is significant because there are many manufacturers who do not offer products in this range and so would be affected only indirectly. Some of these might benefit by the added year of experience gained from the use of PM filters on 175-750 hp engines before PM filters are required on their own products. On the other hand, manufacturers who do not have ready access to this experience base may find themselves at a disadvantage compared to their better-connected competitors.

Although these considerations may be significant, we do not see them as critical to the feasibility and cost impacts of Option 2c. Instead, we believe the primary engine and equipment issues involved in Option 2c are the above-discussed engineering workload impacts caused by the decoupling of PM and NOx standards for 175-750 hp engines, the shortened stability periods for the Tier 3 standards, and the possible feasibility concerns raised by shortened lead time available for transferring technology from the highway sector.

Based on the above discussion and the analyses performed for this option described in this Chapter, we conclude that Option 2c would not be appropriate for proposal, for the same key reasons described above for Option 2b, though to a lesser degree and with a corresponding lesser emission benefit.

12.6.2.2.5 Option 2d

The proposed program does not apply the NOx adsorber-based 0.30 g/bhp-hr NOx standard to engines below 75 hp for reasons explained in Chapter 4 and in section III of the preamble to the proposal. The Option 2d analysis evaluates the environmental and cost impact of applying this standard to 25-75 hp engines, phased in at 50-50-50-100% over 2013-2016, similar to the NOx phase-in approach taken for larger engines, though on a later schedule. Although we do not believe this approach to be appropriate at this time, we have included this matter in the proposed 2007 technology review as discussed in section III.G of the preamble.

The 25-75 hp category comprises a large and growing segment of the nonroad diesel engine population. Although on a per-engine basis these engines typically emit far less NOx over their lifetime than larger engines, they make up a significant NOx source category, as can be seen in comparing the NOx inventory for Option 2d with that for the proposal (see section 12.2). In addition to the NOx reductions, the application of NOx adsorbers to 25-75 hp engines would recover some of the fuel economy impact due to use of actively-regenerated PM filters on these engines.

The application of NOx adsorbers to 25-75 hp engines would add a sizeable cost to these engines. However, we would not expect the added cost for advanced NOx control to include the cost of modifying the engines themselves to accommodate NOx adsorbers (e.g., electronic common rail fuel systems) because these costs would likely be incurred in meeting our proposed 0.02 g/bhp-hr Tier 4 PM standard, as discussed in Chapter 6. Although under Option 2d the 0.30 g/bhp-hr NOx standard for 25-75 hp engines in 2013 would replace the proposed 3.5 g/bhp-hr NOx+NMHC Tier 4 standard in the same year, the cost of meeting the 3.5 g standard (via EGR or equivalent technology) would not be eliminated, because engine-out emissions performance on this order or better must be achieved to meet the 0.30 g standard employing NOx adsorbers with control efficiencies on the order of 90%. (In fact the 50-75 hp engines must meet this 3.5 g standard in 2008 under Tier 3 requirements.)

The Option 2d program would establish a Tier 4 program implementation schedule that stretches out to 2016, well over a decade from today. Although in principle we support the aim of the industries we regulate to have long-term regulatory certainty and stability, we must balance this with the fact that our understanding of how diesel pollution impacts human health and the environment is the subject of numerous ongoing studies and so is likely to develop and evolve over the next few years, and also with the likelihood that the rapid pace of emission control technology development (often with unexpected innovations along the way) will likewise continue to advance in the years ahead. Standard-setting in this rulemaking with 2016 implementation dates may be inadvisable, and better taken up in the 2007 technology review planned in the proposal.

Based on the above discussion and the analyses performed for this option described in this Chapter, as well as the present concerns with technological feasibility voiced in Chapter 4 of this draft RIA and in Chapter III of the preamble, we conclude that Option 2d would not be appropriate for proposal.

12.6.2.2.6 Option 2e

The Option 2e program is identical to the proposal except that no new NOx standards would be set in Tier 4. Any changes in NOx control from these engines would be incidental, resulting from adoption of the test procedure changes for the Tier 4 PM control program. This analytical option obviously presumes that Tier 4 nonroad diesel NOx control would either not be needed to address air quality concerns or would not be feasible (presumptions we believe are unfounded). These issues are discussed in detail in Chapters 2 and 4 of this draft RIA, and in sections II and III of the preamble to the proposal.

We have assumed no changes to the proposed fuel program in analyzing Option 2e because the proposed fuel desulfurization, though critical to enabling high-efficiency NOx exhaust emission control, is also needed to enable PM filter technology as explained in section III.F of the proposal preamble. The first step in the two-step fuel desulfurization proposal is also primarily a PM-focused action. Finally, the fact that we are proposing PM filter-based standards before or coincident with Tier 4 NOx standards in all relevant power categories, means that the timing of fuel changes under a PM-only option would be unchanged from the proposal.

As discussed in Chapter 4, diesel PM filters can be designed to operate effectively with or without the application of NOx adsorbers in the exhaust stream. In fact under the proposal, some engines are expected to employ PM filters without NOx adsorbers for phase-in model years or, for 25-75 hp engines, for all Tier 4 model years. There are economies of integration available to engine designers working to both the PM and NOx control objectives, such as from combining PM and NOx control functions into a single can or even into integrated internal structures, but even so we would expect that PM-only systems would cost significantly less than combined systems. Some engine designs that do not currently employ sophisticated fuel injection controls could conceivably continue without these under a PM-only option, but we believe that the need for active regeneration of PM filters in many nonroad applications, combined with the growing trend toward application of electronic controls for performance reasons or to meet Tier 2/Tier 3 standards, would tend to mitigate this opportunity. Equipment designers would likely see no or only modest cost advantages to PM-only systems beyond the NOx control hardware itself because the Tier 4 program is structured to minimize multiple Tier 4 redesigns as much as possible, and the likelihood of integrated NOx/PM exhaust emission controls reduces the need for additional brackets and the like.

A PM-only program would be expected to result in added operating costs compared to the proposed program due to the increased fuel consumption of PM filter-equipped engines, not offset by the fuel economy gains of NOx adsorber systems. This matter is discussed in detail in Chapter 6.

We believe that Option 2e would be highly inappropriate. In particular, we believe that a lack of new NOx standards in Tier 4 would fail to adequately address the serious air quality concerns discussed in Chapter 2, and to meet our obligations under section 213(a)(3) of the Clean Air Act which requires the Agency to develop standards reflecting the greatest emission reductions feasible, taking cost, noise and safety concerns into consideration. In doing so, consideration of cost is to be a subordinate consideration, unless costs are somehow exorbitant. See, e.g. Husqvarna AB v. EPA, 254 F. 3d 195, 200 (D.C. Cir. 2001); Lignite Energy Council v. EPA, 198 F. 3d 930, 933 (D.C. Cir. 1999). Here, very substantial NOx reductions – on the order of millions of tons – are technically feasible. The costs of achieving these reductions is not exorbitant. Moreover, the Tier 4 proposal would set stringent PM standards to be implemented in the 2011-2014 timeframe, followed by some period of stability before any new standards beyond Tier 4 would take effect, if found appropriate. Not including new NOx standards in this same timeframe would leave the nonroad diesel sector as a dominant source of NOx emissions for many years to come, at a time when other NOx source categories would have finished implementing stringent measures to deal with NOx-related air quality problems.

12.6.2.2.7 Option 3

As described in section 12.1.2 of this chapter, Option 3 is an exemption from regulation in this rule for very high power engines (>750 hp) used in above-ground mining equipment (AGME). Some have expressed the view that the very large off-highway trucks and earth movers, over 750 hp, used in above-ground mine and quarry operations may constitute a special case worthy of special consideration because of a number of factors:

- They operate remote from populated areas;
- They have very low annual sales volumes and therefore high redesign costs;
- They are used in extreme conditions where aftertreatment will not be durable.

However, the above concerns with applying Tier 4 standards to > 750 hp AGME engines must be balanced with the emissions contribution and the health and welfare concerns from the engines, as well as EPA's assessment that Tier 4 standards for the >750 hp engines used in AGME are technologically feasible and otherwise appropriate under the Clean Air Act. It thus appears that any such exemption would lack a convincing legal rationale, given that mining engines have already been held to be properly subject to regulation under section 213, see Engine Manufacturers Ass'n v. EPA, 88 F. 3d 1075, 1098 (D.C. Cir. 1996) and, as explained below, further reductions in PM and NOx emissions from these engines is technically feasible at reasonable cost.

Large nonroad mining equipment is used in many areas spread across the United States. It is often assumed that the very large AGME is concentrated in western states. Information provided to EPA by a nonroad equipment manufacturer who participates in the >750 hp mining equipment market indicates that in the past decade the western states (not including the west coast states) account for nearly 30 percent of the >750 hp AGME sales. However, the eastern US also has a high share of >750 hp mining equipment. Information provided to EPA by a nonroad equipment manufacturer who participates in the >750 hp mining equipment market indicates that in the past decade, more than 40 percent of the >750 hp equipment was sold to the states in the Ohio River valley. Considering the concentration of coal mining in these states the high use of these large machines in the Ohio River valley should not be suprising.[5]

In general, it is reasonable to project that most above-ground mines are not located in urban areas. However, pollution problems such as ozone and haze are not local but regional problems due to the long-range transport of emissions. In addition, mines are not always in remote rural areas but are some times in or near urban areas. In connection with our original nonroad engine rulemaking in 1994, the American Mining Congress submitted as part of its public comment a report from the TRC Environmental Corporation which states that 40 mine sites are located in ozone nonattainment areas.[6] See Engine Manufacturers Ass'n v. EPA, 88 F.

3d at 1098 (national regulation of nonroad engines used in above-ground mining is justified under section 213 because some of those engines are used in nonattainment areas).

Even in the western states, air pollution from mining equipment is a concern for state and tribal air quality agencies. EPA has recently received comments from the Western Regional Air Partnership supporting further controls on nonroad engines, equipment and fuel, specifically including mining equipment, in order to comply with EPA's regional haze regulations.[7]

Another reasons which some have suggested as grounds for exempting >750 hp engines used in AGME from the proposed Tier 4 standards is the low sales volume and high redesign costs of the engines and the equipment. It is generally correct that for this category of nonroad equipment, annual sales volumes are low, typically on the order of 50 or fewer for a given equipment model, and in many cases fewer than 10. Therefore, the costs of equipment redesign must be spread over a small number of sales. Our proposal for the >750 hp category provides significant flexibilites to address these concerns. This includes a phase-in of all standards (not just NOx and VOC) over three years, as well as the provisions for averaging, banking, and trading and the transition program for equipment manufacturers which are discussed in section VII of the proposed preamble. In fact, the >750 hp category is a separate category under the TPEM which would allow many AGME manufacturers to defer using any Tier 4 technology engines for a full seven years, until 2019.

In addition, the costs of equipment redesign must be put in the context of the high sales price of these types of equipment, which is commonly > $1 million. We should also note that exempting > 750 hp engines used in AGME would not reduce the research & development costs for engine manufacturers. Many of these large engines would still need to meet the proposed Tier 4 standards for applications other than AGME, such as cranes, large oil field equipment, and non-mining applications of off-highway trucks, excavators, etc. Table 12.6.2.2.7-1 below is a list of the nonroad equipment categories and estimated 1998 U.S. population used in EPA's NONROAD model which have engines >750 hp, including those we have projected are used in AGME and those which are not (based on our engineering expertise and discussion with engine and equipment manufacturers).

Table 12.6.2.2.7-1
Nonroad Equipment Categories Which Use Engines >750hp and Estimated Population

> 750 hp Equipment Category	Used in Above-ground Mining?	Est. 1998 U.S. Population[a]
Crawler Tractor/Dozers	Yes	6,097
Excavators	Yes	408
Off-Highway Tractors	Yes	848
Off-highway Trucks	Yes	4,574
Rubber Tire Loaders	Yes	2,633
Bore/Drill Rigs	No	911
Chippers/Stump Grinders	No	118
Cranes	No	19
Crushing/Processing Equipment	Yes	4
Forest Eqp - Feller/Bunch/Skidder	No	12
Other Agricultural Equipment	No	2
Other Construction Equipment	No	29
Other Oil Field Equipment	No	969
Railway Maintenance	No	36
Specialty Vehicle Carts	No	50
Trenchers	No	11

[a] Estimated 1998 U.S. populations from EPA’s draft NONROAD2002 emission inventory model

Some engine engine manufacturers have argued that the engines used in the largest mining applications are so large that the aftertreatment systems cannot be scaled up to such sizes and remain durable (though no manufacturer has provided any specific reasons why this would be so, nor have any data been presented). As discussed in Section III.E. of the preamble and in Chapter 4 of this draft RIA, we recognize that many nonroad equipment types experience harsh and sometimes severe operation conditions. However, as discussed in the preamble and in Chapter 4 of this draft RIA, existing data already indicate that aftertreatment systems can be designed to withstand these harsh environments while maintaining their structural integrity. In fact, many of the actual examples of PM filters which have been used have been for mining applications. Systems have been used in a number of underground mining applications in Europe on equipment ranging from 125 to 275 hp for upto 6,900 hours on a single application.[8] One engine manufacturer, Deutz, developed a PM filter system for engines up to 800 hp. The Deutz system utilized two filters for engines greater than approximately 230 hp, and their largest system relied on two filters which were 62.5 liters each and have been used on engines with displacements of 26 liters.[9] Finally, one integrated engine/equipment manufacturer offers an OEM option of a PM filter based system in a number of their equipment types, including mining equipment.[10]

Based on the information available to us and discussed in section III of the preamble and chapter 4 of the RIA, we believe that exhaust aftertreatment systems can be designed to be durable in-use even for the >750hp engines.

Emissions from >750 hp AGME are a significant portion of the NOx and PM inventory from the nonroad diesel engines. Our modeling indicates that these machines, though low in nationwide sales and population, are not an insignificant part of the NOx and PM inventories. Table VI-1 in the preamble for this proposal shows AGME >750 hp represents 13 percent of the net-present value of the NOx reduction and 2 percent of the PM reduction of our proposal. A graphical representation of the impact on the national inventories of exempting these engines can also be seen in Figures 12.2.2.1-1 (NOx) and 12.2.2.2-1 (PM).

Table 12.2.2.1-1 shows an increase in NOx emissions in 2030 of approximately 103,000 tons, and Table 12.2.2.2-1 shows an increase in PM emission in 2030 of approximately 4,000 tons if the >750 hp AGME were exempted. Table 12.2.3-2 shows that the cumulative, undiscounted emission increase which would occur through 2030 if >750 hp AGME engines were exempted is approximately 742,000 tons of NOx and 30,000 tons of PM.

As discussed in Chapter 12.4, we have estimated the net-present value cost through 2030 of the proposed Tier 4 standards for >750 hp AGME and engines at approximately $490 million. The estimated aggregate cost per ton for the proposed Tier 4 standards for >750 hp AGME is $300/ton for NOx+NMHC and $8,300/ton for PM though 2030. The PM cost per ton value is in line with the estimate for our entire proposal, and the NOx+NMHC estimate is well below the values for the entire proposal. There is no rational way that such costs could be considered so hugely exorbitant or disproportionate (the test under the case law cited earlier) as to justify forgoing the large, achievable emission reductions obtainable from these engines.

Finally, as discussed in Chapter 12.3, we have estimated the net-present value of the monetized health benefits for our proposed standards for >750 hp engines used in AGME through 2030 as being approximately $16 billion.

Based on the information available to us, we do not believe this option should be promulgated. The standards we have proposed for >750 hp AGME engines are feasible and very cost-effective. AGME contributes to the same health and welfare concerns as other nonroad diesel engines, massive emission reductions of PM and NOx from these engines are feasible, and the costs we have estimated for controlling these engines are not excessive, exorbitant, or otherwise inappropriate.

12.6.2.2.8 Option 4

In order to enable the high efficiency exhaust emission control technology to begin to be applied to nonroad engines beginning with the 2011 model year, we are proposing that all nonroad diesel fuel produced or imported after June 1, 2010 would have to meet a 15 ppm sulfur cap. Although locomotive and marine diesel engines are similar in size to some of the diesel engines covered in this proposal, there are many differences (e.g., duty cycles, exhaust system design configurations, size, and rebuild and maintenance practices) that have caused us to treat them separately in past EPA programs.[A] For the same reasons, we are not proposing new engine standards today for these engine categories and as a result, are also not proposing that the second step of sulfur control to 15 ppm in 2010 be applied to locomotive and marine fuel. We are proposing to set a sulfur fuel content standard of 500 ppm for fuel used in locomotive and marine diesel applications. This fuel standard is expected to provide considerable sulfate PM benefits regardless of whether or not we also set more stringent emission standards for these engines.

As discussed in Section IV of the preamble, we are also seriously considering extending the 15 ppm standard to locomotive and marine fuel as early as June 1, 2010 as well. There are several advantages associated with this alternative. First, as reflected in Table 12.2.3-2, it would provide over 9,000 tons of additional sulfate PM benefits and over 114,000 tons of additional SO_2 benefits from 2007 to 2030 (calculated as net present value in 2004). The cost for these additional benefits as shown in Section 12.4.3.2 are $1.8 billion. This cost reflects the incremental cost for reducing the sulfur content of locomotive and marine from 500 ppm to 15 ppm - 2.4 c/gal. The cost also reflects an increase in the long-term per gallon cost of all 15 ppm NRLM diesel fuel of 0.2 c/gal due to the fact that higher cost refiners are now required to produce 15 ppm diesel fuel.

Second, reducing sulfur content of locomotive and marine diesel fuel to 15 ppm in 2010 would simplify the fuel distribution system and the design of the fuel program proposed today since a marker would not be required for locomotive and marine diesel fuel. The marker cost itself is an estimated 0.2 c/gal. While difficult to quantify, additional cost savings would be realized by allowing locomotive and marine fuel to be fungible with nonroad and highway diesel fuel. Furthermore, prices do not necessarily follow costs, and there is reason to believe that the price for 500 ppm locomotive and marine fuel will not necessarily be appreciably lower than if it were required to be 15 ppm. Under the proposal, we expect that a certain amount of marine fuel will be ultra-low sulfur fuel regardless of the standard due to limitations in the production and distribution of unique fuel grades. Where 500 ppm fuel is available, the possible suppliers of fuel will likely be more constrained, limiting competition and allowing prices to approach that of 15 ppm fuel. If we were to bring locomotive and marine fuel to 15 ppm, the pool of possible suppliers could expand beyond those today, since highway diesel fuel will also be at the same standard. It is difficult to provide any quantitative price comparison, but it is entirely possible that the price differential between a 15 ppm and 500 ppm standard for locomotive and marine fuel would be significantly less than the estimated 2.4 c/gal cost differential.

Third, reducing sulfur content of locomotive and marine diesel fuel to 15 ppm in 2010 would help reduce the potential opportunity for misfueling of 2007 and later model year highway vehicles and 2011 and later model year nonroad equipment with higher sulfur fuel. We do not

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[A] Locomotives, in fact, are treated separately from other nonroad engines and vehicles in the Clean Air Act, which contains provisions regarding them in section 213(a)(5). Less than 50 hp marine engines were included in the 1998 final rule for nonroad diesel engines, albeit with some special provisions to deal with marine-specific engine characteristics and operating cycles.

anticipate misfueling to be a significant concern under today's proposal, since by 2010 more than 80% of the total number 2 distillate pool is expected to be 15 ppm (see Table 7.1-16 in Chapter 7). Nevertheless, extending the 15 ppm standard to locomotive and marine would increase this percentage to more than 85%, further limiting the sources of fuel on which misfueling could occur either accidentally or intentionally.

Finally, reducing sulfur content of locomotive and marine diesel fuel to 15 ppm in 2010 would allow refiners to coordinate plans to reduce the sulfur content of all of their nonroad diesel fuel at one time. While in many cases this may not be a significant advantage, it may be a more important consideration here since it is probably not a question of whether locomotive and marine fuel must meet a 15 ppm cap, but merely when. As discussed in Section IV of the preamble, it is the Agency's intention to take action in the near future to set new emission standards for locomotive and marine engines that could require the use of high efficiency exhaust emission control technology, and thus, also require the use of 15 ppm sulfur diesel fuel.[B] We anticipate that such engine standards would likely take effect in the 2011-13 timeframe, requiring 15 ppm locomotive and marine diesel fuel in the 2010-12 timeframe.

However, discussions with refiners have suggested there are significant advantages to leaving locomotive and marine diesel fuel at 500 ppm, at least in the near-term and until we set more stringent standards for those engines. First, the locomotive and marine diesel fuel markets could provide a market for off-specification product that is important for refiners, particularly during the transition to 15 ppm for highway and nonroad diesel fuel in 2010. It is possible that significant volumes of 500 ppm diesel fuel would be created in the distribution system during the distribution of 15 ppm fuel. For example, the pipeline interface between 15 ppm diesel fuel and higher sulfur jet fuel would likely contain less than 500 ppm sulfur. Without the ability to sell this fuel to the locomotive and marine diesel fuel markets, this interface would have to be sold as heating oil. The available markets for heating oil could be quite limited, particularly outside the Northeast, causing more fuel to have to be shipped back to refineries for reprocessing at considerable expense. Maintaining a market for locomotive and marine fuel at 500 ppm would provide a market across much of the country where off-specification 15 ppm could be marketed. Waiting just a year or two beyond 2010 for implementing the 15 ppm standard for locomotive and marine would not address long term desires for outlets for off-specification product, but it would address the more critical, near term needs during the transition. Second, waiting just another year or two beyond 2010 is projected to allow virtually all refiners to take advantage of the new lower cost desulfurization technologies. As discussed in Chapter 6 approximately 80 percent of refineries are projected to be able to take advantage of these new technologies with the June 1, 2010 implementation date. We project that just a two year delay to 2012 would permit all refineries to do so, thereby reducing the desulfurization costs for 15 ppm locomotive and marine fuel. Finally, while the monetized benefits of controlling the sulfur level of locomotive

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[B] The most recent new standards for locomotives and marine diesel engines (including those under 50 hp) were set in separate actions (63 FR 18977, April 16, 1998 and 67 FR 68241, November 8, 2002).

and marine diesel fuel from 500 ppm down to 15 ppm outweigh the costs (even in the absence of new engine emission standards), the cost per ton for the incremental sulfate PM and SO_2 emission reductions as shown in Table 12.5-1 is $64,000 and 10,300 per ton, respectively. These costs are rather high in comparison to other possible control options.

12.6.2.2.9 Option 5a

The Option 5a program is identical to the proposal except that no new program requirements would be set in Tier 4 for engines under 75 hp. Instead Tier 2 standards and testing requirements for engines under 50 hp, and Tier 3 standards and testing requirements for 50-75 hp engines, would continue indefinitely. This analytical option presumes that Tier 4 nonroad diesel NOx and PM control from these engines would either not be needed to address air quality concerns or would not be feasible (presumptions we believe are unfounded). These issues are discussed in detail in Chapters 2 and 4 of this draft RIA, and in sections II and III of the preamble to the proposal.

We believe that Option 5a would be inappropriate. As discussed in section III.E of the proposal preamble, the 0.02 g/bhp-hr PM standard proposed for 25-75 hp engines in 2013 is feasible, based on the use of high-efficiency PM filters and the availability of nonroad diesel fuel with sulfur levels capped at 15 ppm. As also discussed in section III.E of the proposal preamble, the less stringent PM standards proposed for engines under 75 hp in 2008 are feasible, based on the use of diesel oxidation catalysts and/or engine optimization strategies, and on the availability of nonroad diesel fuel with sulfur levels capped at 500 ppm. In fact, as discussed in section III.E of the proposal preamble, some of today’s engines already meet the proposed standards. We believe that the 2008 standards provide a reasonable means of gaining substantial PM reductions from the nonroad diesel sector in the early years of the Tier 4 program, while managing the workload, stability, and technology transfer issues involved, but we are also requesting comment in section III.B.1.d.ii of the proposal preamble on whether it would be better not to set a Tier 4 PM standard in 2008 so that engine designers could instead focus their efforts on meeting a PM-filter based standard for these engines earlier, say in 2012.

Establishing no Tier 4 PM program at all for engines under 75 hp would, on the other hand, leave engines under 50 hp at Tier 2 PM standards levels of 0.60 g/bhp-hr (for <25 hp) and 0.45 g/bhp-hr (for 25-50 hp), and would leave 50-75 hp engines at a Tier 3 PM standard level of 0.30 g/bhp-hr. The resulting in-use emissions levels from these engines would be many times higher than that achieved under the proposed program. As discussed in section 12.2, the overall loss in Tier 4 PM emissions reductions would be correspondingly large, both in the early and the long-term timeframes of the program. This option would also fail to address toxic hydrocarbon concerns, considering the large population of these under 75 hp engines and the fact that they are often used in populated areas and in equipment without closed cabs.

To take no action on under 75 hp engines in this rulemaking would compromise air quality goals and would also greatly increase uncertainty for the engine and equipment manufacturing industry. Due to the continuing growth in sales of these smaller engines and the promising developments that are occurring in diesel emissions control technology, it seems improbable that putting off action to some point in the future would result in more flexibility, more leadtime, or less stringent standards than under this proposal. We believe instead that setting standards now, with plans for a technology review in 2007 for the long-term (2013) standards, appropriately balances the need for Tier 4 program certainty and leadtime with the Agency's commitment to reconsider program requirements where necessary in light of continuing technology progress and demonstration over the next few years.

12.6.2.2.10 Option 5b

The Option 5b program is identical to the proposal except that for engines under 75 hp only the 2008 engine standards would be set. There would be no additional PM filter-based standard in 2013 for 25-75 hp engines, and no additional NOx+NMHC standard in 2013 for 25-50 hp engines. This analytical option presumes that controlling PM from 25-75 hp engines to levels achievable with PM filters would either not be needed to address air quality concerns or would not be feasible (presumptions we believe are unfounded). These issues are discussed in detail in Chapters 2 and 4 of this draft RIA, and in sections II and III of the preamble to the proposal.

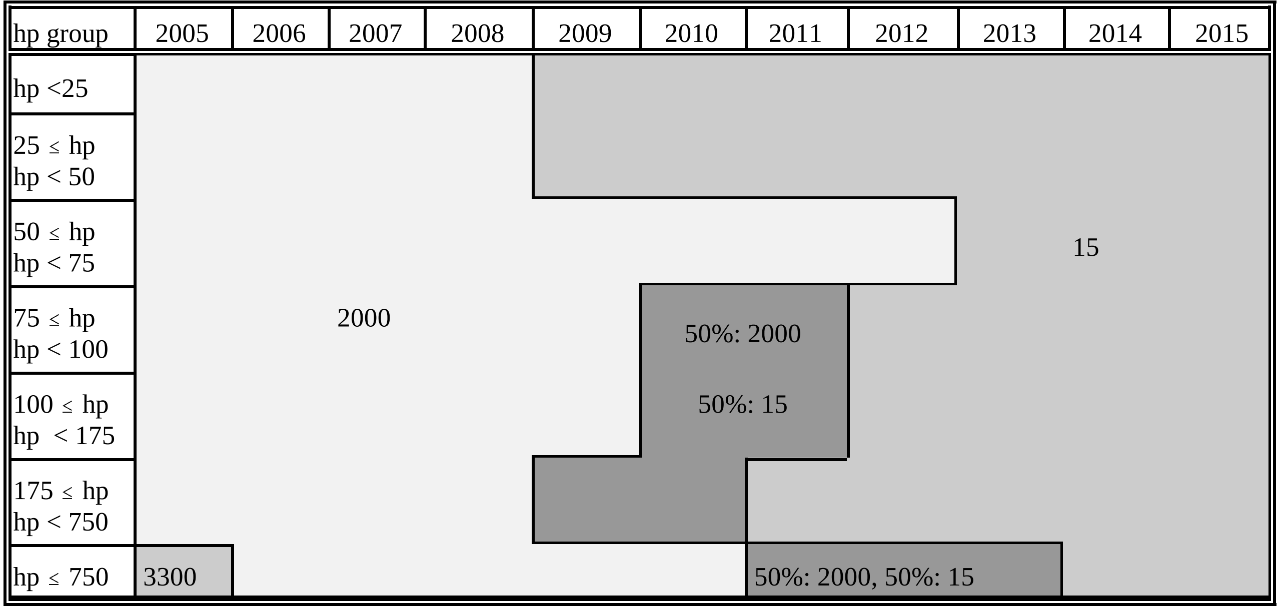
Although, unlike Option 5a, Option 5b does involve important PM reductions beginning in 2008, much of the Option 5a discussion in section 12.6.2.2.9 applies here as well. The loss in long-term Tier 4 PM emissions reductions would be large, as discussed in section 12.2, because the PM reductions from engines produced after 2008 would be only on the order of 50% compared to previous-tier engines, instead of the more than 95% reductions available through the use of PM filters. This option could also leave a large unaddressed toxic hydrocarbon concern, depending on the degree to which manufacturers choose to meet the 2008 standards through the use of diesel oxidation catalysts. Overall, we believe that Option 5b would be inappropriate.

Appendix 12A: Certification Fuel Sulfur Levels

The sulfur levels assumed for certification fuel for the purposes of modeling emission benefits of each program option are presented in this appendix. Note that the Tier 1 standards for >750hp engines continued through 2005. Manufacturers subject to these Tier 1 standards are assumed to have certified on fuel having an average sulfur content of 3300ppm, based on existing records of those tests.

As described in Section 12.2.1.1, the cert fuel sulfur levels in the charts below do not always coincide with changes in the required maximum sulfur level for certification fuel. Engine manufacturers are unlikely to make modifications to their engines to take advantage of the lower sulfur requirement for cert fuel until new engine standards make such modifications necessary. The assumed cert fuel sulfur levels were used to establish the proper zero-hour emission factors for new engines. For in-use inventory impacts of these new engines, the emission factors were further adjusted to account for the assumed in-use sulfur levels. Thus, for instance, engines certified on 2000ppm sulfur fuel and then operated on 500ppm fuel would realize a PM benefit relative to the PM certification standard.

Figure 12A-1
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 1 (ppm)



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	2000	15	15	15	15	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	2000	15	15	15	15	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	2000	2000	2000	2000	2000	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	2000	2000	50%: 2000 50%: 15	50%: 2000 50%: 15	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	50%: 2000 50%: 15	50%: 2000 50%: 15	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	50%: 2000 50%: 15	50%: 2000 50%: 15	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

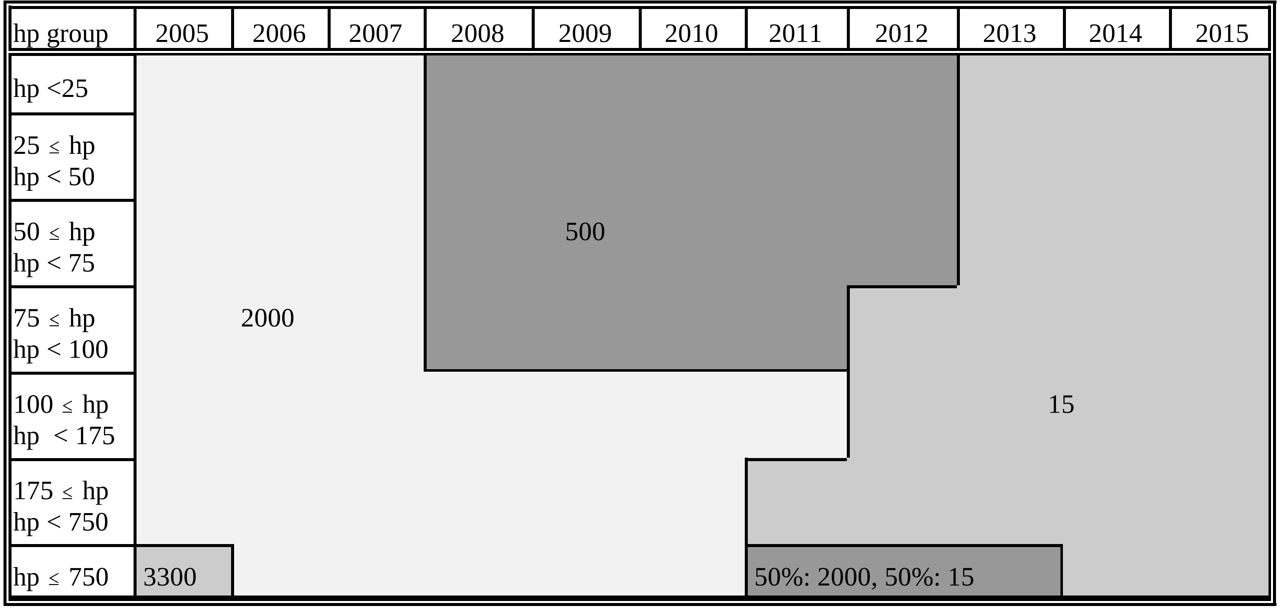
Figure 12A-2
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 1a (ppm)

hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	2000	2000	15	15	15	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	2000	2000	15	15	15	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	2000	2000	15	15	15	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	2000	2000	15	15	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	15	15	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	15	15	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	15	15	15	15	15	15	15

Figure 12A-3
Assumed Certification Fuel Sulfur Levels for Modeling Under Option 1b (ppm)

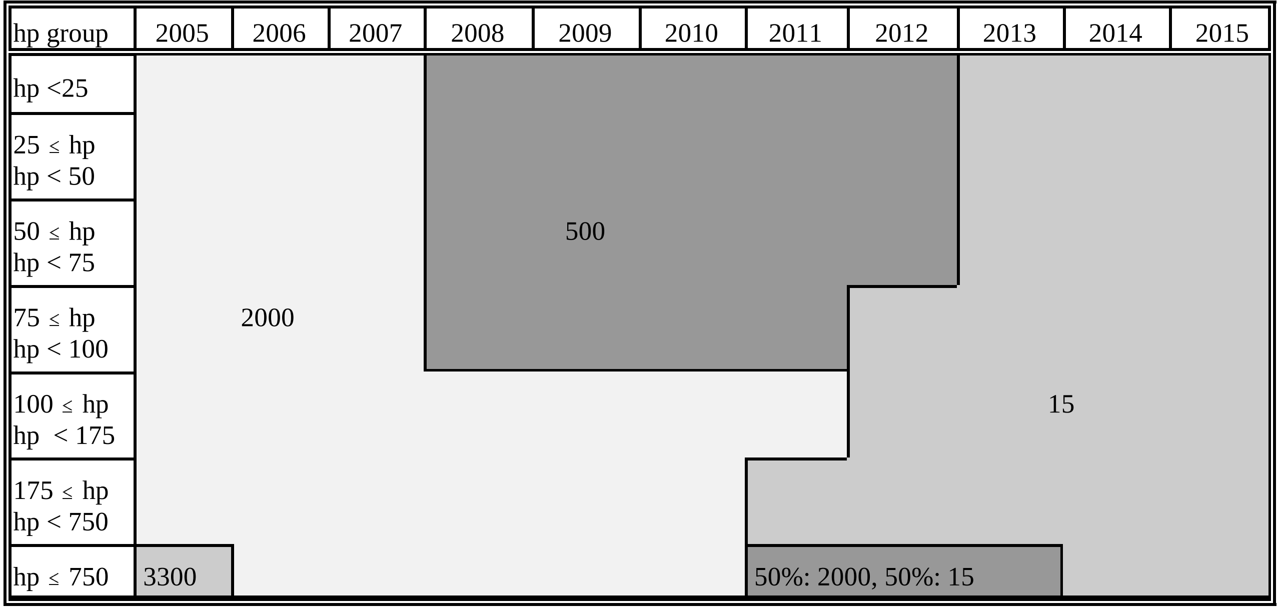
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	2000	2000	15	15	15	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	2000	2000	15	15	15	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	2000	2000	15	15	15	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	2000	2000	15	15	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	15	15	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	15	15	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	15	15	15	15	15	15	15

Figure 12A-4
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Proposed Program (ppm)



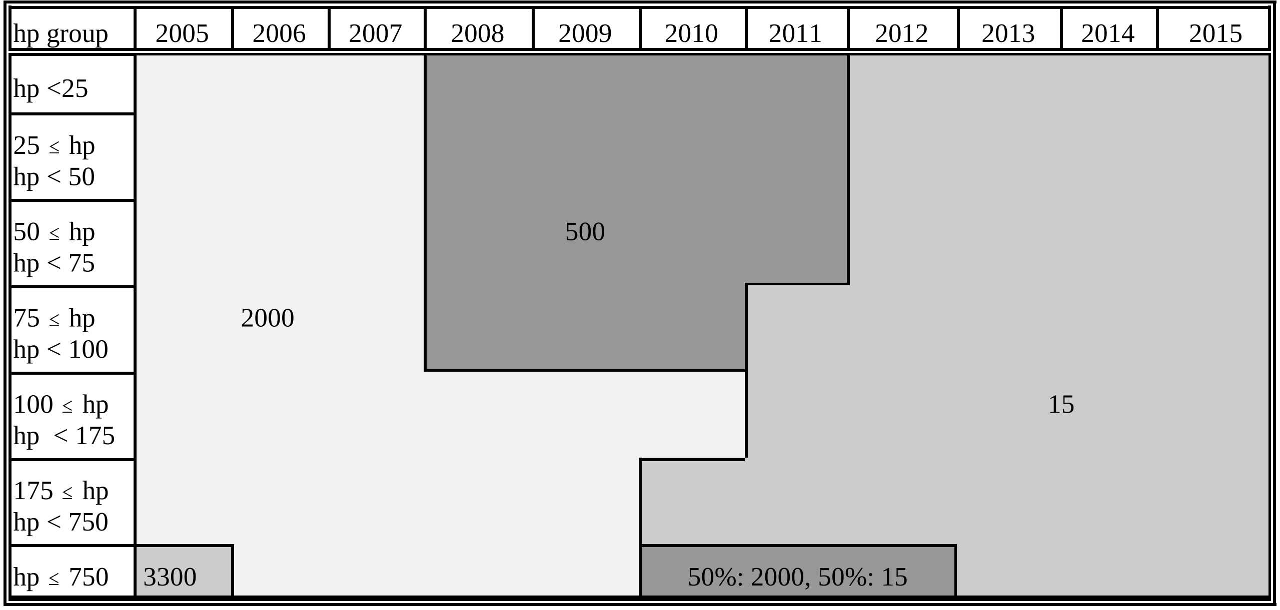
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-5
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 2a (ppm)



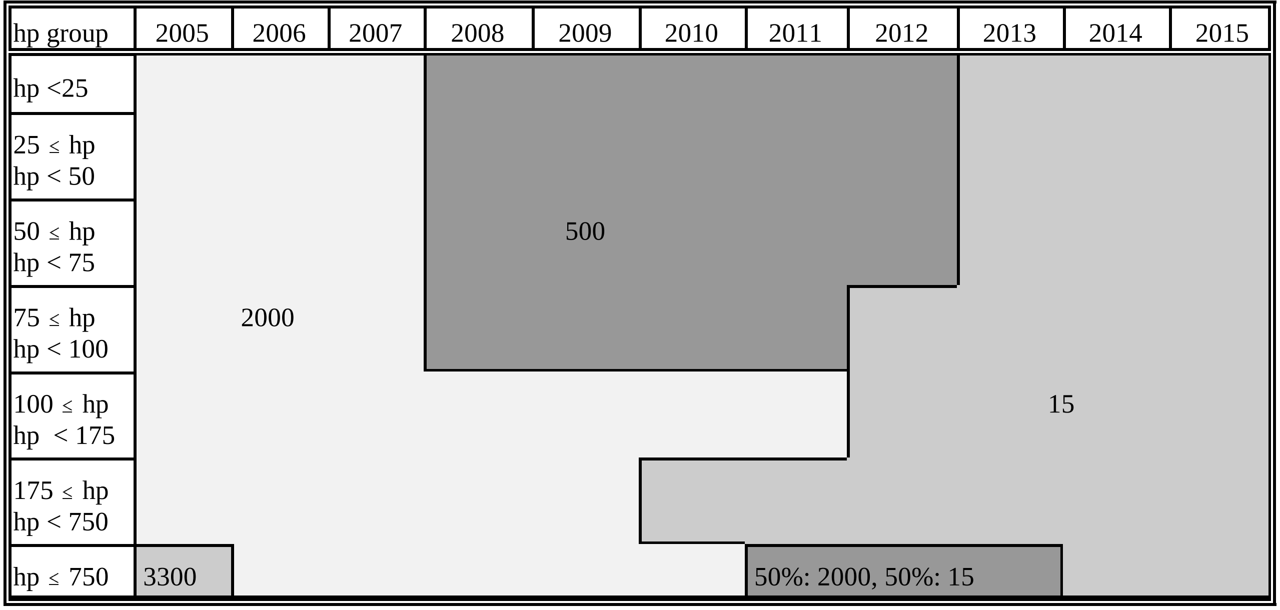
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-6
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 2b (ppm)



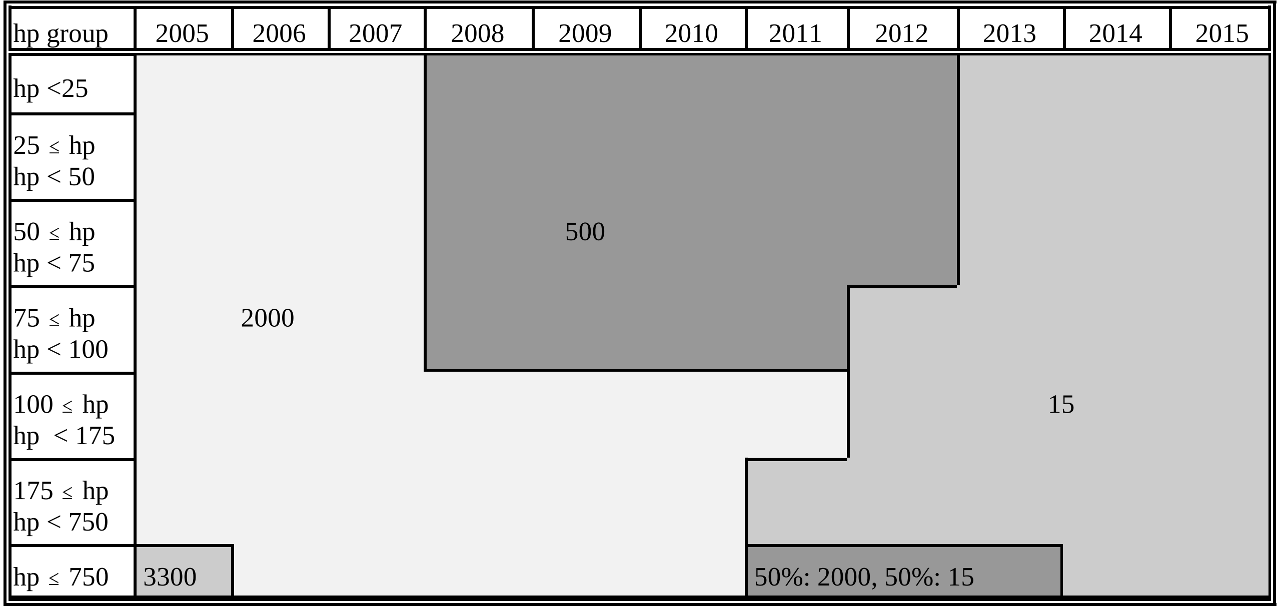
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	15	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	15	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	15	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	15	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	15	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	15	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15	15

Figure 12A-7
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 2c (ppm)



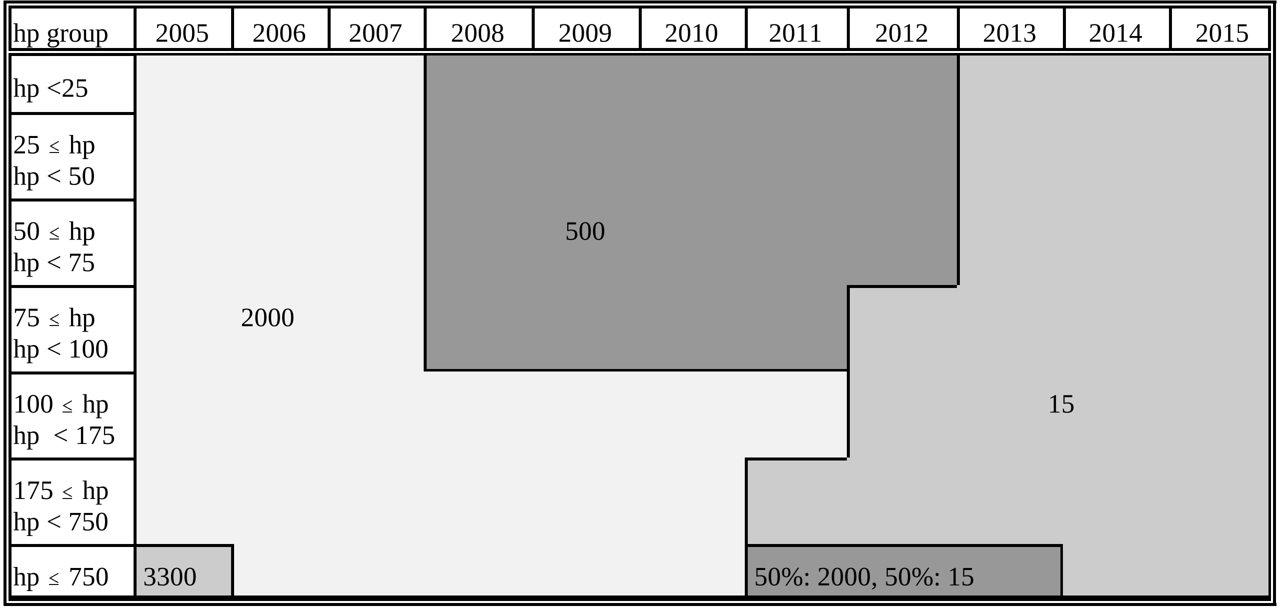
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	15	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-8
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 2d (ppm)



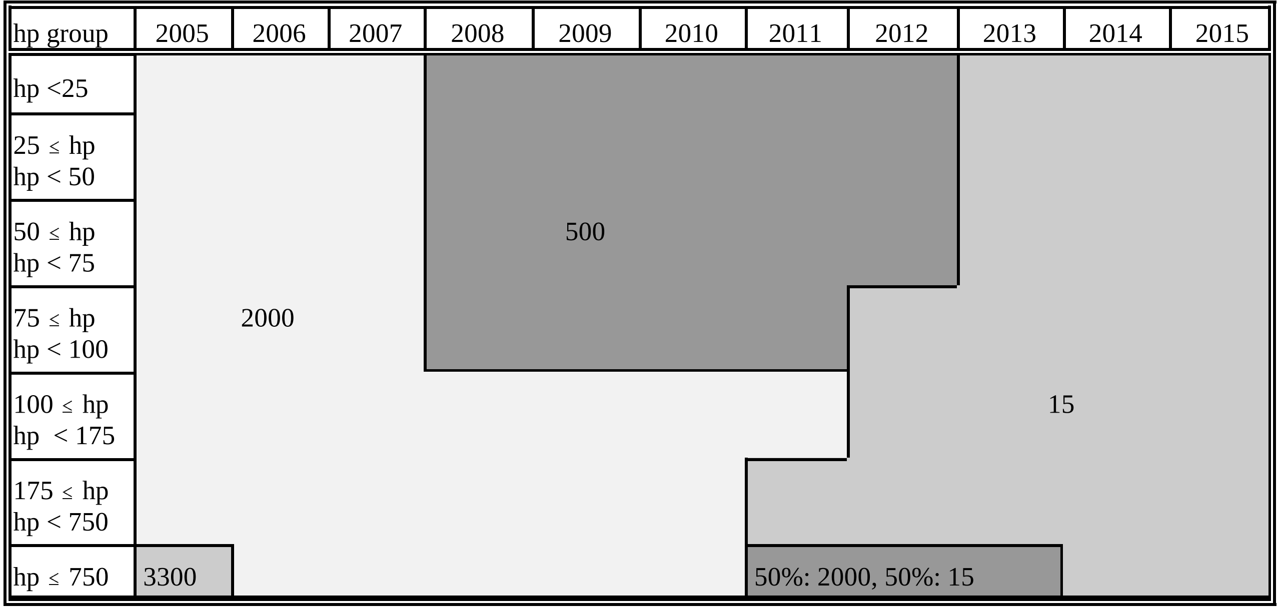
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-9
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 2e (ppm)



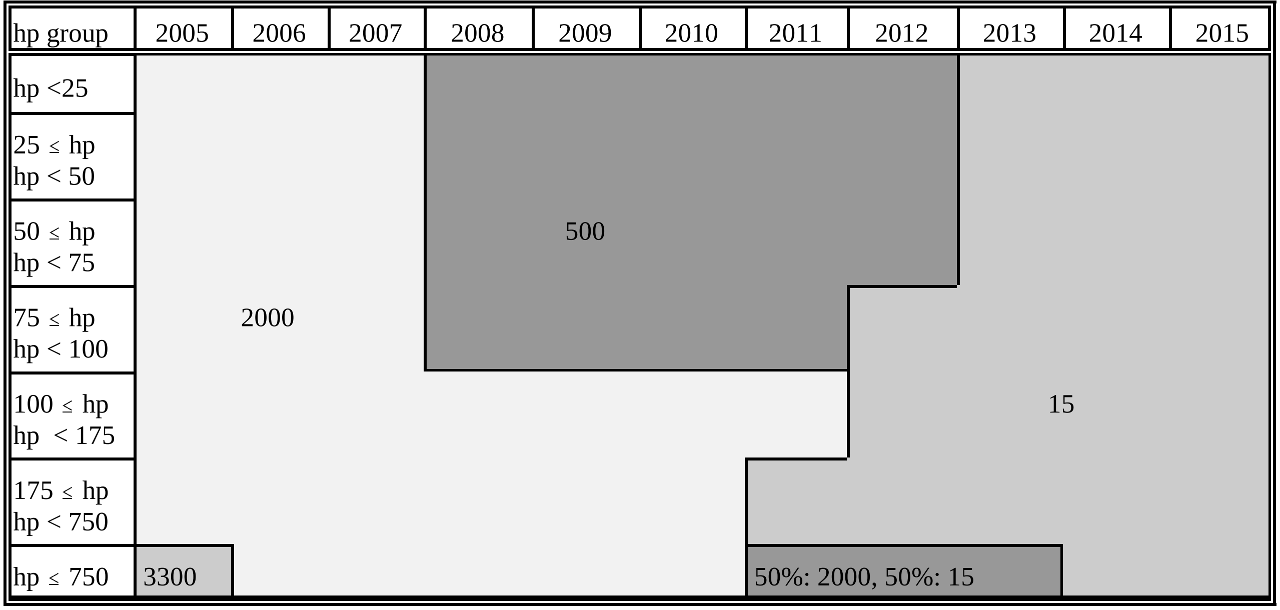
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-10
Assumed Certification Fuel Sulfur Levels f To Establish
Zero Hour Emission Factors Under Option 3 (ppm)



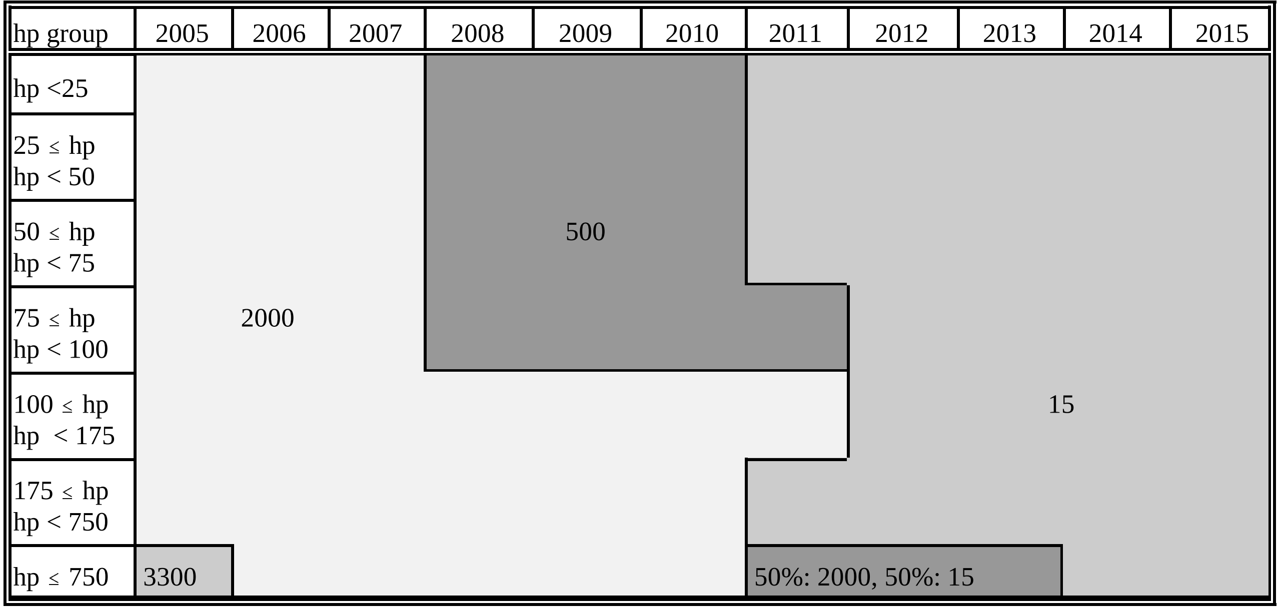
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-11
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 4 (ppm)



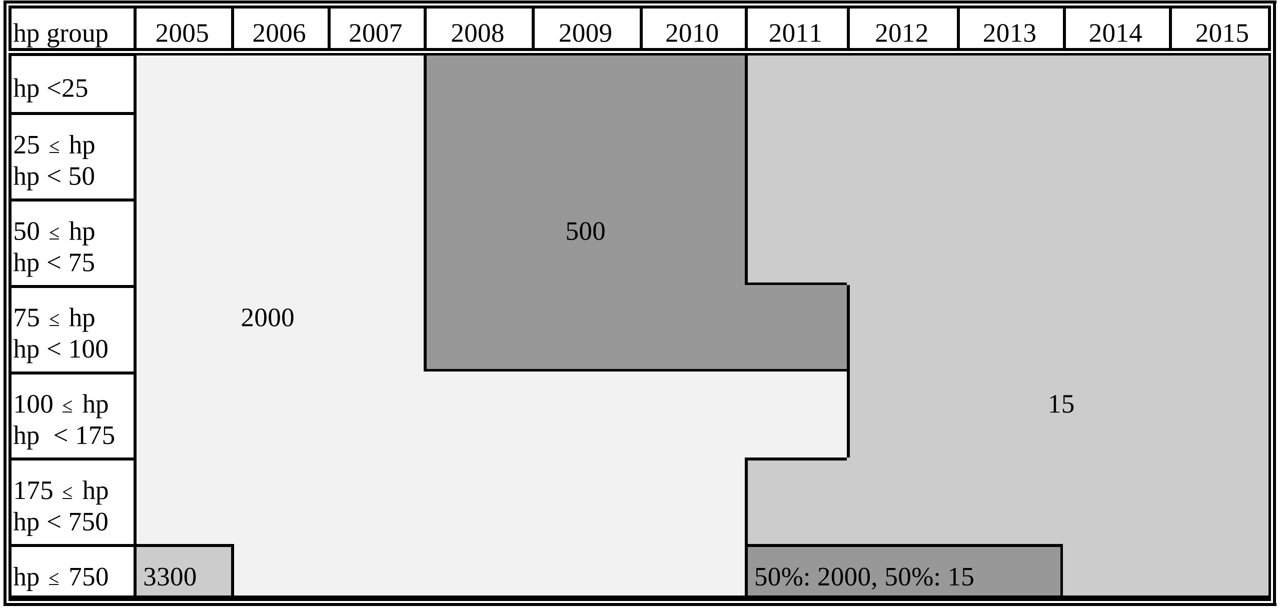
hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	500	500	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	500	500	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	500	500	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-12
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 5a (ppm)



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	15	15	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	15	15	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	15	15	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Figure 12A-13
Assumed Certification Fuel Sulfur Levels To Establish
Zero Hour Emission Factors Under Option 5b (ppm)



hp group	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
hp <25	2000	2000	2000	500	500	500	15	15	15	15	15
25 ≤ hp hp < 50	2000	2000	2000	500	500	500	15	15	15	15	15
50 ≤ hp hp < 75	2000	2000	2000	500	500	500	15	15	15	15	15
75 ≤ hp hp < 100	2000	2000	2000	500	500	500	500	15	15	15	15
100 ≤ hp hp < 175	2000	2000	2000	2000	2000	2000	2000	15	15	15	15
175 ≤ hp hp < 750	2000	2000	2000	2000	2000	2000	15	15	15	15	15
hp ≤ 750	3300	2000	2000	2000	2000	2000	50%: 2000, 50%: 15	50%: 2000, 50%: 15	50%: 2000, 50%: 15	15	15

Appendix 12B: Incremental Cost, Emission Reductions, Benefits, and Cost Effectiveness

This Appendix provides incremental costs, incremental emission reductions, marginal cost per ton of emission reduction, and incremental benefits for each in a series of potential control steps. The cost, emission reduction, and cost per ton data are presented in Table 12B-1, and the cost and benefit data are presented in Table 12B-2.

Because the emission reductions represent the change from the preceding baseline level, the order of the control steps affects the estimate of cost per ton. Some, but not all, of the steps specified in Table 12B-1 are components of our proposal. The data presented in Table 12B-1 and 12B-2 are provided as additional information for the reader.

For each control step, the baseline emission levels are presented prior to the introduction of that control step. The first baseline level in the table represents the emissions levels absent any new controls for nonroad engines or nonroad, locomotive and marine fuels. Subsequent baseline levels represent the difference between the preceding baseline level and the reductions from the preceding control steps (i.e., the remaining emissions).

The costs in the table represent approximate costs for each control step, apportioned among various pollutants. Our method for apportioning costs to a particular pollutant is described in Chapter 8, Table 8.1-2. In this case, the apportioning of costs is simplified, somewhat, as each control step has a distinct pollutant focus (i.e., the applications of DOCs/engine-out reductions and CDPFs for PM, even though some NMHC reductions are realized). The costs shown here should be considered as rough approximations, because they have been derived from our program costs by splitting various fixed costs of the program by pollutant and control step. For example, the R&D costs estimated in Chapter 6, and used here, for engines larger than 75 hp were roughly split 67 percent to NOx control and 33 percent to PM control. We have made no estimate of the distinct cost of only doing PM control or only doing NOx control for engines in this horsepower range. We believe that it is likely that R&D costs for either step alone would be higher than represented in this analysis. Nevertheless, for comparative purposes we have presented the costs here.

Table 12B-1
Incremental Cost, Emissions Reductions, and Cost Effectiveness for Various Control Steps
(All values are expressed as 2004 NPV using a 3 percent discount rate)

Control Steps		**PM** (NPV 2007-2030)	**NOx+NMHC** (NPV 2007-2030)	**SO2** (NPV 2007-2030)
500 ppm Sulfur Nonroad, Locomotive, and Marine Fuel in 2007	Baseline	3,251	21,745	5,273
	Cost	-	-	$0.5
	Reductions	374	0	4,638
	Cost/Ton	-	-	$100
15 ppm Sulfur Nonroad Fuel and Tier 4 PM for >75hp Engines	Baseline	2,877	21,745	635
	Cost	$9.9	-	-
	Reductions	917	137	315
	Cost/Ton	$10,800	-	-
Transitional PM Standards for <75hp in 2008	Baseline	1,960	21,608	320
	Cost	$1.2	-	-
	Reductions	88	1	0
	Cost/Ton	$14,200	-	-
CDPF based PM Standards for 25hp - 75hp in 2013	Baseline	1,872	21,608	320
	Cost	$2.2	-	-
	Reductions	121	0	0
	Cost/Ton	$18,300	-	-
Tier 4 NOx Standards	Baseline	1,751	21,608	320
	Cost	-	$3.3	-
	Reductions	0	5,407	0
	Cost/Ton	-	$600	-
15 ppm Sulfur Locomotive and Marine Fuel in 2010	Baseline	1,751	16,200	320
	Cost	$0.6	-	$1.2
	Reductions	9	0	114
	Cost/Ton	$64,200	-	$10,300
Remaining tons NR, Locomotive and Marine		1,742	16,200	206

Baseline - the NPV of the emission levels prior to the control step (1,000 tons), recalculated after each control step
Cost - the NPV of the annualized costs of the control step ($ billion), apportioned by pollutant
Reductions - the NPV of the emissions reductions from the baseline due to the control step (1,000 tons)
Cost/Ton - the ratio of the Cost and Reductions ($/ton)

The reduction rows in the table represent the emission reductions from the previous baseline level by pollutant for each of the control steps. The cost per ton row simply reflects the ratio of the preceding two rows, defining the cost per ton of reduction realized in the control step. Note that for many of the control steps, reductions in emissions are realized for multiple pollutants, yet we have attributed cost to only one or two pollutants (depending on the primary purpose of the control technology, as discussed in Chapter 8.1). This does not mean that the reductions in the other pollutants can actually be realized for free, only that we have attributed no costs to those reductions. For example, we have attributed all of the costs of the 15 ppm sulfur program to PM control, therefore the “Tier 4 NOx Standards” data shows very low $/ton incremental costs.

Estimates of the cost and dollar benefits of the various control steps are presented in Table 12B-2, below. The cost estimates are the same as for Table 12B-1 (although summed into a single value rather than distributed across multiple pollutants). The benefits estimates are an approximation based upon the benefits estimates for the proposal and the various control options presented previously in Section 12.3 Benefits Comparison. Each of these control steps can be approximated by one or more of the options in Table 12.6-1. For example, the PM portion, of control step, *Transitional PM Standards for <75 hp in 2008*, can be found as the difference between options 5a (no control for <75hp engines) and 5b (no CDPF control for 25hp-75hp engines). As these benefits are based on approximations from other control approaches, the benefits listed in Table 12B-2 should be considered as approximate estimates to the benefits of the various control steps.

Table 12B-2
Cost and Benefits of Various Control Steps
(All values are expressed as 2004 NPV using a 3 percent discount rate)

Control Steps	**Cost ($ Billion) NPV(2007-2030)**	**Benefit ($ Billion) NPV(2007-2030)**
500 ppm Sulfur Nonroad, Locomotive, and Marine Fuel in 2007	$0.5	$230
15 ppm Sulfur Nonroad Fuel and Tier 4 PM for >75 hp Engines	$9.9	$186
Transitional PM Standards for <75hp in 2008	$1.2	$28
CDPF based PM Standards for 25hp - 75hp in 2013	$2.2	$43
Tier 4 NOx Standards	$3.3	$64
15ppm Sulfur Locomotive and Marine Fuel in 2010	$1.8	$6

Chapter 12 References

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2. Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines, November 1999, p. 79 (Docket A-97-50, Document V-B-01).

3. Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines, November 1999, p. 79 (Docket A-97-50, Document V-B-01).

4. Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines, November 1999, p. 79 (Docket A-97-50, Document V-B-01).

5. “Information Regarding Mine Locations in the United States”, EPA Memorandum. Copy available in EPA Air Docket A-2001-28

6. "Analysis of Nonroad Engine Emissions in the Mining Industry," TRC Environmental Corporation, July 1993, p. 1.

7. January 28, 2003 letter from the Western Regional Air Partnership to Administrator Whitman. Copy available in EPA Air Docket A-2001-28.

8. “Particulate Traps for Retro-Fitting Construction Site Engines VERT” Final Measurements and Implementation”, A. Mayer et. al., SAE paper 1999-01-0116, March 1999. See also “Particulate Traps for Construction Machines: Properties and Field Experience”, J. Czerwinski et. al., SAE Paper 2000-01-1923.

9. “The Optimized Deutz Service Diesel Particulate Filter System II”, H. Houben et. al., SAE Technical Paper 942264, 1994. See also **“**Summary of Conference Call between US EPA and Deutz Corporation on September 19, 2002 regarding Deutz Diesel Particulate Filter System”, EPA Memorandum to Air Docket A-2001-28”.

10. “Particulate Traps for Construction Machines: Properties and Field Experience”, J. Czerwinski et. al., SAE Paper 2000-01-1923.