Draft Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder

EPA
United States
Environmental Protection
Agency

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

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List of Acronyms

µm	Micrometers
(bext)	Light-Extinction Coefficient
µg	Microgram
µg/m3	Microgram per Cubic Meter
AAR	Association of American Railroads
ABT	Average Banking and Trading
ACS	American Cancer Society
AEO	Annual Energy Outlook (an EIA publication)
AESS	Automatic Engine Stop/Start System
AIM	2-28
AIRS	Aerometric Information Retrieval System
APHEA	Air Pollution and Health: A European Approach
AQ	Air Quality
AQCD	Air Quality Criteria Document
AQMTSD	Air Quality Modeling Technical Support Document
ARB	(California) Air Resources Board
ASLRRA	American Short Line and Regional Railroad Association
ASPEN	Assessment System for Population Exposure Nationwide
ATAC	Average Total Cost
avg	Average
BenMAP	Benefits Mapping and Analysis Program
bhp	Brake Horsepower
BNSF	Burlington Northern Santa Fe
BSFC	Brake Specific Fuel Consumption
BTS	Bureau of Transportation
C	Celsius
C1	Category 1
C2	Category 2
C3	Category 3
CA	California
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule (CAIR) (70 FR 25162, May 12, 2005)
CAMR	Clean Air Mercury Rule
CAND	Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004)
CARB	California Air Resources Board
CASAC	Clean Air Scientific Advisory Committee
CAVR	Clean Air Visibility Rule
CB	Chronic Bronchitis
CCV	Closed Crankcase Ventilation
CDC	Centers for Disease Control
CDPF	Catalyzed Diesel Particulate Filter
CEA	Cost Effective Analysis
CES	Constant Elasticity of Substitution
CFR	Code of Federal Regulations
CI	Compression Ignition (i.e., diesel engines)
CI	Confidence Interval
CIMT	Carotid Intima-Media Thickness
CITT	Chemical Industry Institute of Toxicology
CMAQ	Community Multiscale Air Quality
CMB	Chemical Mass Balance
CN	Canadian National Railroad
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COI	Cost of Illness

COPD	Chronic Obstructive Pulmonary Disease
CPI-U	Consumer Price Index - All Urban Consumers
C-R	Concentration Response
CSS	Coastal Sage Scrub
CUA	Cost Utility Analysis
cyl	Cylinder
D	Demand
DE	Diesel Exhaust
DEM	Domestic Engine Manufacturer
diff	Difference
disp	Displacement
DOC	Diesel Oxidation Catalyst
DOE	Department of Energy
DOT	Department of Transportation
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
DR	Discount Rate
DRIA	Draft Regulatory Impact Analysis
DV	Design Values
EAC	Early Action Component
EC	Elemental Carbon
EF	Emission Factor
EGR	Exhaust Gas Recirculation
EIA	Energy Information Administration (part of the U.S. Department of Energy)
EIA	Economic Impact Analysis
EIM	Economic Impact Model
EMD	Electromotive Diesel
EMS-HAP	Emissions Modeling System for Hazardous Air Pollution
EO	Executive Order
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 2005
ESPN	EPA speciation network
F	Fahrenheit
FEM	Foreign Engine Manufacturer
FEV	Functional Expiratory Volume
FR	Federal Register
FRA	Federal Railroad Administration
FRM	Final Rulemaking
FRP	Fiberglass-Reinforced Plastic
g	Gram
g/bhp-hr	Grams per Brake Horsepower Hour
g/kW-hr	Grams per Kilowatt Hour
gal	Gallon
GAO	Government Accountability Office
GDP	Gross Domestic Product
GEOS	Goddard Earth Observing System
GETS	General Electric Transportation Systems
GIS	Geographic Information System
H_2	Hydrogen Gas
HAD	Diesel Health Assessment Document
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HD	Heavy-Duty
HEI	Health Effects Institute
HEP	Head End Power
HES	Health Effects Subcommittee

hp	Horsepower
hp-hrs	Horsepower Hours
hrs	Hours
IARC	International Agency for Research on Cancer
ICD	International Classification of Diseases
IMO	International Maritime Organization
IMPROVE	Interagency Monitoring of Protected Visual Environments
IRIS	Integrated Risk Information System
ISCST3	Industrial Source Complex Short Term Model
ISORROPIA	Inorganic Aerosol Thermodynamic Model
JAMA	Journal of the American Medical Association
K	Kelvin
k	Thousand
km	Kilometer
kW	Kilowatt
kWH	Kilowatt Hour
L	Liter
lb	Pound
LM	Locomotive and Marine
LRS	Lower Respiratory Symptoms
LSD	Low Sulfur Diesel fuel
m3	Cubic Meters
MARAD	U.S. Maritime Administration
MARPOL	The International Convention for the Prevention of Pollution of Ships
MC	Marginal Cost
MCIP	Meteorology-Chemistry Interface Processor
MECA	Manufacturers of Emission Controls Association
mg	Milligram
MI	Myocardial Infarction
MILY	Morbidity Inclusive Life Years
min	Minute
MM	Million
MM-1	Inverse Megameter
MOBILE6	Vehicle Emission Modeling Software
MRAD	Minor Restricted Activity Days
MSAT	Mobile Source Air Toxic
MSAT1	2001 Mobile Source Air Toxics Rule
MSB	Major Shipbuilding Base
MVUS	Merchant Vessels of the U. S.
MW	Megawatt
MW-hrs	Megawatt Hours
N	Nitrogen
N_2	Nitrogen Molecule
NA	Not Applicable
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NATA	National Air Toxic Assessment
NBER	National Bureau of Economic Research
NCDC	National Clean Diesel Campaign
NCI	National Cancer Institute
NCLAN	National Crop Loss Assessment Network
NEI	National Emissions Inventory
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emissions Standards for Hazardous Air Pollutants

NH_3	Ammonia
NIOSH	National Institute of Occupational Safety and Health
NLEV	National Low Emission Vehicle
NMHC	Non-Methane Hydrocarbons
NMIM	National Mobile Inventory Model (EPA software tool)
NMIM2005	National Mobile Inventory Model Released in 2005
NMMA	National Marine Manufacturers Association
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NO	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NONROAD	EPA's Non-road Engine Emission Model
NONROAD2005	EPA's Non-road Engine Emission Model Released in 2005
NOx	Oxides of Nitrogen
NPRM	Notice of Proposed Rulemaking
NPV	Net Present Value
NRC	National Research Council
NREC	National Railway Equipment Co
NRLM	Nonroad, Locomotive and Marine diesel fuel
NRT4	Nonroad Tier 4 Rule
NSTC	National Science and Technology Council
NTE	Not To Exceed
O&M	Operating and maintenance
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards
OC	Organic Carbon
ºCA	Degree Crank Angle
OEHHA	Office of Environmental Health Hazard Assessment
OEM	Original Equipment Manufacturer
OMB	Office of Management and Budget
OTAQ	Office of Transportation and Air Quality
P	Price
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PGM	Platinum Metals Group
PM	Particulate Matter
PM AQCD	EPA Particulate Matter Air Quality Criteria Document
PM/NMHC	Particulate Matter to Non-Methane Hydrocarbon Ratio
PM10	Coarse Particulate Matter (diameter of 10 µm or less)
PM2.5	Fine Particulate Matter (diameter of 2.5 µm or less)
PMM	Post-Manufacturer Marinizer
PMNAAQS	Particulate Matter National Ambient Air Quality Standards
POM	Polycyclic Organic Matter
ppb	Parts per Billion
PPI	Producer Price Index
ppm	Parts per Million
psi	Pounds per Square Inch
PSR	Power Systems Research
Q	Quantity
QALY	Quality Adjusted Life Years
R&D	Research and Development
RfC	Reference Concentration
RFA	Regulatory Flexibility Analysis
RFS	Renewable Fuels Standard
RIA	Regulatory Impact Analysis
rpm	Revolutions per Minute

RPO	Regional Planning Organization
RRF	Relative Reduction Factors
RV	Revision
RVP	Reid Vapor Pressure
S	Sulfur
S	Supply
SAB	Science Advisory Board
SAB-HES	Science Advisory Board - Health Effects Subcommittee
SAE	Society of Automotive Engineers
SAPS	Sulfated-Ash, Phosphorus, and Sulfur Content
SBA	Small Business Administration
SBREFA	Small Business Regulatory Enforcement Fairness Act
SCC	Source Classification Code
SCR	Selective Catalyst Reduction
SI	Spark Ignition
SIC	Standard Industrial Classification
SiC	Silicon Carbide
SMAT	Speciated Modeled Attainment Test
SO_2	Sulfur Dioxide
SOx	Oxides of Sulfur
SOA	Secondary Organic Carbon Aerosols
SOF	Soluble Organic Fraction
STB	Surface Transportation Board
SVOC	Semi-Volatile Organic Compound
SwRI	Southwest Research Institute
TBN	Total Base Number
TCC	Total Compliance Cost
TCM	Total Carbon Mass
TDC	Top Dead Center
TFM	Transportacion Ferroviaria Mexicana
THC	Total Hydrocarbon
TSD	Technical Support Document
TVCC	Total Variable Compliance Cost
ULSD	Ultra Low Sulfur Diesel fuel
UP	Union Pacific Railroad
URS	Upper Respiratory Symptoms
USDA	United States Department of Agriculture
UV	Ultraviolet
UV-b	Ultraviolet-b
VOC	Volatile Organic Compound
VOF	Volatile Organic Fraction
VSL	Value of Statistical Life
WLD	Work Loss Days
WTP	Willingness-to-Pay
$2,005	U.S. Dollars in calendar year 2005

Executive Summary

The Environmental Protection Agency (EPA) is proposing a comprehensive three-part program to reduce emissions of particulate matter (PM) and oxides of nitrogen (NO_x) from locomotives and marine diesel engines below 30 liters per cylinder displacement. Locomotives and marine diesel engines designed to these proposed standards would achieve PM reductions of 90 percent and NO_x reductions of 80 percent, compared to engines meeting the current Tier 2 standards. The proposed standards would also yield sizeable reductions in emissions of nonmethane hydrocarbons (NMHC), carbon monoxide (CO), and hazardous compounds known as air toxics.

This proposal is part of EPA's ongoing National Clean Diesel Campaign (NCDC) to reduce harmful emissions from diesel engines of all types. The anticipated emission reductions will significantly reduce exposure to harmful pollutants and also provide assistance to states and regions facing ozone and particulate air quality problems that are causing a range of adverse health effects, especially in terms of respiratory impairment and related illnesses.

This Regulatory Impact Analysis provides technical, economic, and environmental analyses of the proposed emission standards. Chapter 1 provides industry characterization for both the locomotive and marine industry. Chapter 2 presents air quality modeling results and describes the health and welfare effects associated with particulate matter (PM), ozone, and air toxics. Chapter 3 provides our estimates of the current emission inventories and the reductions that can be expected from the proposed standards. Chapter 4 contains our technical feasibility justification for the emission limits, and Chapter 5 contains the estimated costs of complying with those standards. Chapter 6 presents the estimated societal benefits of the proposed rulemaking. Chapter 7 contains our estimates of the market impacts of the proposed standards and the distribution of costs among stakeholders. Finally, Chapter 8 contains our analysis of several alternative control scenarios we considered during the development of this proposal.

1. Proposed Emission Standards

The proposed program addresses emissions from all types of diesel locomotives, including line-haul, switch, and passenger rail, and all types of marine diesel engines below 30 liters per cylinder displacement (collectively called "marine diesel engines.").[A] These include marine propulsion engines used on vessels from recreational and small fishing boats to super-yachts, tugs and Great Lakes freighters, and marine auxiliary engines ranging from small gensets to large generators on ocean-going vessels. Each of these markets is described in Chapter 1.

We are proposing a comprehensive three-part emission control program for locomotives and for marine diesel engines that will dramatically reduce the emissions from these sources. The standards and our technical feasibility justification are contained in Chapter 4.

The first part consists of near-term engine-out emission standards, referred to as Tier 3 standards, for newly-built locomotives and marine diesel engines. These standards reflect the application of engine-out PM and NO_x reduction technologies and begin to phase in starting in 2009. The second part consists of longer-term standards, referred to as Tier 4 standards, for newly-built locomotives and marine diesel engines. These standards phase in over time, beginning in 2014. For most engines, these standards are similar in stringency to the final standards included in the 2007 highway diesel and Clean Air Nonroad Diesel programs and are expected to require the use of high-efficiency aftertreatment systems to ensure compliance. These standards will be enabled by the availability of ultra-low sulfur diesel fuel (ULSD. Third, we are proposing to tighten emission standards for existing locomotives when they are remanufactured. Also included in our proposal are provisions to eliminate emissions from unnecessary locomotive idling, and we are requesting comment on applying standards to certain existing marine diesel engines when they are manufactured.

Locomotive Standards

The proposed standards for newly-built line-haul, passenger, and switch locomotives and for existing 1973 and later Tier 0, Tier 1, and Tier 2 locomotives are set out in Tables 1 and 2. With some exceptions, these standards would apply to all locomotives that operate extensively within the United States. Exceptions include historic steam-powered locomotives and locomotives powered solely by an external source of electricity. The regulations also generally do not apply to existing locomotives owned by railroads that are classified as small businesses. In addition, engines used in locomotive-type vehicles with less than 750 kW (1006 hp) total power (used primarily for railway maintenance), engines used only for hotel power (for passenger railcar equipment), and engines that are used in self-propelled passenger-carrying railcars, are excluded from these regulations. The engines used in

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[A] In this RIA, "marine diesel engine" refers to compression-ignition marine engines below 30 liters per cylinder displacement unless otherwise indicated. Engines at or above 30 liters per cylinder are being addressed in separate EPA actions.

these smaller locomotive-type vehicles are generally subject to our nonroad engine requirements (40 CFR Parts 89 and 1039).

Table ES-1 – Proposed Standards for New and Existing Line-Haul and Passenger Locomotives (g/bhp-hr)

STANDARDS APPLY TO:	DATE	PM	NO_x	HC
Remanufactured Tier 0 & 1	2008 as available, 2010 required	0.22	7.4 [a]	0.55 [a]
Remanufactured Tier 2	2008 as available, 2013 required	0.10	5.5	0.30
New Tier 3	2012	0.10	5.5	0.30
New Tier 4	PM and HC 2015 NOx 2017	0.03	1.3	0.14

(a) For Tier 0 locomotives originally manufactured without a separate loop intake air cooling system, these standards are 8.0 and 1.00 for NO_X *and HC, respectively.*

Table ES-2 – Proposed Standards for New and Existing Switch Locomotives (g/bhp-hr)

SWITCH LOCOMOTIVE STANDARDS APPLY TO:	DATE	PM	NO_x	HC
Remanufactured Tier 0	2008 as available, 2010 required	0.26	11.8	2.10
Remanufactured Tier 1	2008 as available, 2010 required	0.26	11.0	1.20
Remanufactured Tier 2	2008 as available, 2013 required	0.13	8.1	0.60
New Tier 3	2011	0.10	5.0	0.60
New Tier 4	2015	0.03	1.3	0.14

Marine Standards

The proposed standards for newly-built marine diesel engines are set out in Tables 3, 4, 5, and 6. The Tier 3 standards would apply to all marine diesel engines with per cylinder displacement up to 30 liters. The Tier 4 standards would apply only to commercial marine diesel engines above 600 kW and recreational marine diesel engines above 2,000 kW.

For the purposes of this emission control program, Category 1 marine diesel engines are those with per cylinder displacement up to 7 liters. Category 2 marine diesel engines are those with per cylinder displacement from 7 to 30 liters. High power density engines are those with a power density above 35 kW/liter).

Table ES-3 – Proposed Tier 3 Standards for Marine Diesel C1

RATED KW	L/CYLINDER	PM G/BHP-HR	NO_x+HC G/BHP-HR	MODEL YEAR
<19 kW	<0.9	0.30	5.6	2009
19 - <75 kW	<0.9 [a]	0.22	5.6	2009
		0.22 [b]	3.5 [b]	2014
75 - 3700 kW	<0.9	0.10	4.0	2012
	0.9- <1.2	0.09	4.0	2013
	1.2- <2.5	0.08 [c]	4.2	2014
	2.5- <3.5	0.08 [c]	4.2	2013
	3.5- <7.0	0.08 [c]	4.3	2012

(a) <75 kW engines at or above 0.9 L/cylinder are subject to the corresponding 75-3700 kW standards.
(b) Option: 0.15 PM / 4.3 NO_X in 2014.
(c) This standard level drops to 0.07 in 2018 for <600 kW engines.

Table ES-4 – Proposed Tier 3 Standards for Marine Diesel C1 Recreational and Commercial High Power Density

RATED KW	L/CYLINDER	PM G/BHP-HR	NO_x+HC G/BHP-HR	MODEL YEAR
<19 kW	<0.9	0.30	5.6	2009
19 - <75 kW	<0.9 [a]	0.22	5.6	2009
		0.22 [b]	3.5 [b]	2014
75 - 3700 kW	<0.9	0.11	4.3	2012
	0.9- <1.2	0.10	4.3	2013
	1.2- <2.5	0.09	4.3	2014
	2.5- <3.5	0.09	4.3	2013
	3.5- <7.0	0.09	4.0	2012

(a) <75 kW engines at or above 0.9 L/cylinder are subject to the corresponding 75-3700 kW standards.
(b) Option: 0.15 PM / 4.3 NO_X+HC in 2014.

Table ES-5 – Proposed Tier 3 Standards for Marine Diesel C2

RATED KW	L/CYLINDER	PM G/BHP-HR	NO_x+HC G/BHP-HR	MODEL YEAR
=<3700 kW	7- <15	0.10	4.6	2013
	15- <20	0.20 [a]	6.5 a	2014
	20- <25	0.20	7.3	2014
	25- <30	0.20	8.2	2014

(a) For engines at or below 3300 kW in this group, the PM / NO_X+HC Tier 3 standards are 0.25 / 5.2.

Table ES-6 – Proposed Tier 4 Standards for Marine Diesel C1 and C2

RATED KW	PM G/BHP-HR	NO_x G/BHP-HR	HC G/BHP-HR	MODEL YEAR
>3700 kW	0.09 [a]	1.3	0.14	2014
	0.04	1.3	0.14	2016 [b]
1400 - 3700 kW	0.03	1.3	0.14	2016 [c]
600 - <1400 kW	0.03	1.3	0.14	2017 [b]

(a) This standard is 0.19 for engines with 15-30 liter/cylinder displacement.
(b) Optional compliance start dates are proposed within these model years; see discussion below.
(c) Option for engines with 7-15 liter/cylinder displacement: Tier 4 PM and HC in 2015 and Tier 4 NO_X in 2017.

2. Projected Inventory and Cost Impacts

Our analysis of the projected impacts of the proposed standards can be found in Chapter 2 (air quality impacts), Chapter 3 (inventory impacts) and Chapter 6 (benefits).

Inventory Reductions

A discussion of the estimated current and projected inventories for several key air pollutants are contained in Chapter 3. Nationally, in 2007 these engines account for about 20 percent of mobile source NO_x emissions and 25 percent of mobile source diesel $PM_{2.5}$ emissions. Absent new emissions standards, we expect overall emissions from these engines to remain relatively flat over the next 10 to 15 years due to existing regulations such as lower fuel sulfur requirements and the phase-in of locomotive and marine diesel Tier 1 and Tier 2 engine standards but starting in about 2025 emissions from these engines would begin to grow. Without new controls, by

2030, these engines would become a large portion of the total mobile source emissions inventory constituting 35 percent of mobile source NO_x emissions and 65 percent of diesel PM emissions.

We estimate that the proposed standards would reduce annual NO_x emissions by about 765,000 tons and $PM_{2.5}$ and 28,000 tons in 2030**.** Table 7 shows the emissions reductions associated with today's proposal for selected years, and the cumulative reductions through 2040 discounted at 3 and 7 percent. These reductions in PM and NO_x levels would produce nationwide air quality improvements.

Table ES-7 – Estimated Emissions Reductions Associated with the Proposed Locomotive and Marine Standards (Short tons)

YEAR	$PM_{2.5}$	PM_{10} [A]	NO_x	NMHC
2015	7,000	7,000	84,000	14,000
2020	15,000	15,000	293,000	25,000
2030	28,000	29,000	765,000	39,000
2040	38,000	40,000	1,123,000	50,000
NPV at 3%	315,000	325,000	7,869,000	480,000
NPV at 7%	136,000	140,000	3,188,000	216,000

a Note that, $PM_{2.5}$ is estimated to be 97 percent of the more inclusive PM_{10} emission inventory. In Section II we generate and present $PM_{2.5}$ inventories since recent research has determined that these are of greater health concern. Traditionally, we have used PM_{10} in our cost effectiveness calculations. Since cost effectiveness is a means of comparing control measures to one another, we use PM_{10} in our cost effectiveness calculations for comparisons to past control measures.

Engineering Costs

The engineering cost analysis for the proposed standards can be found in Chapter 5. The total engineering costs associated with today's proposal are the summation of the engine and equipment compliance costs, both fixed and variable, the operating costs, and the costs associated with the locomotive remanufacturing program. These costs are summarized in Table 8.

Table ES-8 – Total Engineering Costs of the Proposal ($Millions)

YEAR	ENGINE COSTS	EQUIPMENT COSTS	OPERATING COSTS	COSTS OF REMANUFACTURING PROGRAM	TOTAL COSTS
2011	$99	$0	$11	$97	$207
2012	$55	$0	$13	$75	$142
2015	$100	$25	$25	$31	$181
2020	$87	$10	$187	$15	$250
2030	$105	$8	$407	$85	$605
2040	$104	$8	$611	$153	$876
NPV at 3%	$1,678	$141	$4,039	$1,374	$7,233
NPV at 7%	$883	$71	$1,596	$682	$3,231

These engineering costs are allocated to NO_x and PM reductions in Table 9. About half of the costs of complying with the program are operating costs, with the bulk of those being urea-related costs associated with SCR technology. Since SCR is a technique for reduce NO_x emissions, this means that most of the operating costs and, therefore, the majority of the total engineering costs of the program are associated with NO_x control.

Table ES-9 – Total Engineering Costs, Allocated by Pollutant ($Millions)

YEAR	PM COSTS	NO_x COSTS
2011	$93	$113
2012	$62	$80
2015	$93	$88
2020	$836	$164
2030	$159	$446
2040	$218	$658
NPV at 3%	$2,222	$5,011
NPV at 7%	$1,068	$2,163

Cost per Ton of Reduced Emissions

Using the inventory and engineering cost information, we can estimate the cost per ton of pollutant reduced as a result of the proposed standards. Table 10 contains the estimated cost per ton of pollutant reduced based on the net present value of the engineering costs and inventory reductions from 2006 through 2040. This estimate captures all of the engineering costs and emissions reductions including those associated with the locomotive remanufacturing program. Table 10 also presents the estimated cost per ton of pollutant reduced for 2030 using the annual costs and emissions reductions in that year alone. That estimates includes engineering costs and emission reductions that will occur from the new engine standards and locomotive remanufacturing program in that year.

Table ES-10 – Proposed Program Cost per Ton Estimates

POLLUTANT	2006 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 3%	2006 THRU 2040 DISCOUNTED LIFETIME COST PER TON AT 7%	LONG-TERM COST PER TON IN 2030
NO_x+NMHC	$600	$630	$550
PM	$6,840	$7,640	$5,560

3. Estimated Benefits and Economic Impacts

Estimated Benefits

We estimate that the requirements in this proposal will result in substantial benefits to public health and welfare and the environment, as described in Chapter 6. The benefits analysis performed for this proposal uses sophisticated air quality and benefit modeling tools and is based on peer-reviewed studies of air quality and health and welfare effects associated with improvements in air quality and peer-reviewed studies of the dollar values of those public health and welfare effects.

EPA typically quantifies PM- and ozone-related benefits in its regulatory impact analyses (RIAs) when possible. In the analysis of past air quality regulations, ozone-related benefits have included morbidity endpoints and welfare effects such as damage to commercial crops. EPA has not recently included a separate and additive mortality effect for ozone, independent of the effect associated with fine particulate matter. For a number of reasons, including 1) advice from the Science Advisory Board (SAB) Health and Ecological Effects Subcommittee (HEES) that EPA consider the plausibility and viability of including an estimate of premature mortality associated with short-term ozone exposure in its benefits analyses and 2) conclusions regarding the scientific support for such relationships in EPA's 2006 Air Quality Criteria for Ozone and Related Photochemical Oxidants (the CD), EPA is in the process of determining how to appropriately characterize ozone-related mortality benefits within the context of benefits analyses for air quality regulations. As part of this process, we are seeking advice from the National Academy of Sciences (NAS) regarding how the ozone-mortality literature should be used to quantify the reduction in premature mortality due to diminished exposure to ozone, the amount of life expectancy to be added and the monetary value of this increased life expectancy in the context of health benefits analyses associated with regulatory assessments. In addition, the Agency has sought advice on characterizing and communicating the uncertainty associated with each of these aspects in health benefit analyses.

Since the NAS effort is not expected to conclude until 2008, the agency is currently deliberating how best to characterize ozone-related mortality benefits in its rulemaking analyses in the interim. For the analysis of the proposed locomotive and marine standards, we do not quantify an ozone mortality benefit. So that we do not provide an incomplete picture of all of the benefits associated with reductions in emissions of ozone precursors, we have chosen not to include an estimate of total ozone benefits in the proposed RIA. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards. Our analysis, however, indicates that the rule's monetized $PM_{2.5}$ benefits alone substantially exceed our estimate of the costs.

The range of benefits associated with the proposed program are estimated based on the risk of several sources of PM-related mortality effect estimates, along with all other PM non-mortality related benefits information. These benefits are presented in Table ES-11. The benefits reflect two different sources of information about the impact of reductions in PM on reduction in the risk of premature death, including both the American Cancer Society (ACS) cohort study and an expert elicitation study conducted by EPA in 2006. In order to provide an indication of the sensitivity of the benefits estimates to alternative assumptions, in Chapter 6 of the RIA we present a variety of benefits estimates based on two epidemiological studies (including the ACS Study and the Six Cities Study) and the expert elicitation. EPA intends to ask the Science Advisory Board to provide additional advice as to which scientific studies should be used in future RIAs to estimate the benefits of reductions in PM. These estimates are in year 2005 dollars.

Table ES-11– Estimated Monetized PM-Related Health Benefits of the Proposed Locomotive and Marine Engine Standards

	TOTAL BENEFITS[A,B,C,D] (BILLIONS 2005$)	
	2020	2030
PM mortality derived from the ACS cohort study; Morbidity functions from epidemiology literature		
Using a 3% discount rate	$4.4+B	$12+B
Confidence Intervals (5th - 95th %ile)	($1.0 - $10)	($2.1 - $27)
Using a 7% discount rate	$4.0+B	$11+B
Confidence Intervals (5th - 95th %ile)	($1.0 - $9.2)	($1.8 - $25)
PM mortality derived from lower bound and upper bound expert-based result;[e] Morbidity functions from epidemiology literature		
Using a 3% discount rate	$1.7+B - $12+B	$4.6+B - $33+B
Confidence Intervals (5th - 95th %ile)	($0.2 - $8.5) – ($2.0 - $27)	($1.0 - $23) – ($5.4 - $72)
Using a 7% discount rate	$1.6+B - $11+B	$4.3+B - $30+B
Confidence Intervals (5th - 95th %ile)	($0.2 - $7.8) – ($1.8 - $24)	($1.0 - $21) – ($4.9 - $65)

[a] Benefits include avoided cases of mortality, chronic illness, and other morbidity health endpoints.

[b] PM-related mortality benefits estimated using an assumed PM threshold of 10 μg/m3. There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 6.6.1.3 of the RIA.

[c] 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 Chapter 6 of the RIA.

[d] Results reflect the use of two different discount rates: 3 and 7 percent, which are recommended by EPA’s Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

[e] The effect estimates of nine of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. One of the experts fall below this range and two of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts’ judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of benefits estimates associated with each of the twelve expert responses can be found in Tables 6.4-3 and 6.4-4 in the RIA.

We estimate that the annual emission reductions associated with the proposed standards would annually prevent 1,500 premature deaths (based on the ACS cohort study), 170,000 work days lost, and 1,000,000 minor restricted-activity days. Using the ACS-based estimate of PM-related premature mortality incidence, we estimate that the monetized benefits of this rule in 2030 would be approximately $12 billion, assuming a 3 percent discount rate (or $11 billion assuming a 7 percent discount rate). Using the range of results derived from the expert elicitation, we estimate that the monetized benefits in 2030 would range from approximately $4.6 billion to $33 billion, assuming a 3 percent discount rate (or $4.3 to $30 billion assuming a 7 percent discount rate). These estimates would be increased substantially if we were to adopt the remanufactured marine engine program concept. The annual cost of the program in 2030 would be significantly less, at approximately $600 million.

Economic Impact

We also performed an economic impact analysis to estimate the market and social welfare impacts of the proposed standards. This analysis can be found in Chapter 7. According to this analysis, the average price of a locomotive in 2030 is expected to increase by less than three percent as a result of the proposed standards. The average price of a commercial marine diesel engine in 2030 is expected to increase by about 8.5 percent for Category 1 engines above 800 hp and about 19 percent for Category 2 engines above 800 hp.[B] The average price of a marine vessel using those engines is expected increase by about 1 percent for vessels using Category 1 engines above 800 hp (about $16,000) and about 3.6 percent for vessels using Category 2 engines above 800 hp (about $142,000). Increases in engine and vessel prices for commercial engines below 800 hp and recreational engines are expected to be negligible.

Overall, producers and consumers of rail and marine transportation services are expected to bear the majority of the social costs of the program, in large part because they bear the operating (urea) and remanufacturing costs that make up most of the compliance costs of the proposal. Providers of those transportation services are expected to bear about 42 percent of the social costs of the rule, and users are expected to bear about 50 percent. However, the price of rail and transportation services is expected to increase by less than 1 percent. Locomotive, marine diesel engine, and marine vessel manufacturers will bear the remainder of the social costs.

4. Alternative Program Options

In the course of designing our proposed program, we investigated several alternative approaches to both the engine and fuel programs. Chapter 8 contains a description of these alternatives and an analysis of their potential costs and benefits.

[B] Marine diesel engines are divided into three categories for the purposes of EPA's standards. Category 1 are engines above 50 hp and up to 5 liters per cylinder displacement. Category 2 are engines from 5 to 30 liters per cylinder. Category 3 are engines at or above 30 liters per cylinder. See 40 CFR 94.2. Note that we are proposing to change the definition of Category 1 and Category 2 engines to reflect a 7 liter per cylinder cut-off.

CHAPTER 1: INDUSTRY CHARACTERIZATION

CHAPTER 1: Industry Characterization

In order to assess the impacts of emission regulations upon the affected industries, it is important to understand the nature of the industries impacted by the regulations. The industries affected by these regulations include marine diesel engine manufacturers and marinizers, the manufacturers of marine vessels which have marine diesel marine engines installed on them, the manufacturers of locomotives and locomotive engines, the owners and operators of locomotives (i.e., railroads), and remanufacturers of locomotives and locomotive engines. This chapter provides market information for each of these affected industries, and is provided for background purposes.

1.1 Marine

1.1.1 Introduction

The regulations for marine diesel engines will directly impact three industries. These industries are the manufacturers of marine diesel engines, diesel engine marinizers, and the manufacturers of vessels which have marine diesel engines installed on them. Each of these industries is discussed in more detail in the following sections. Much of this marine industry characterization was taken from a report done for us by RTI, International.[1]

1.1.1.1 Marine Diesel Market Overview

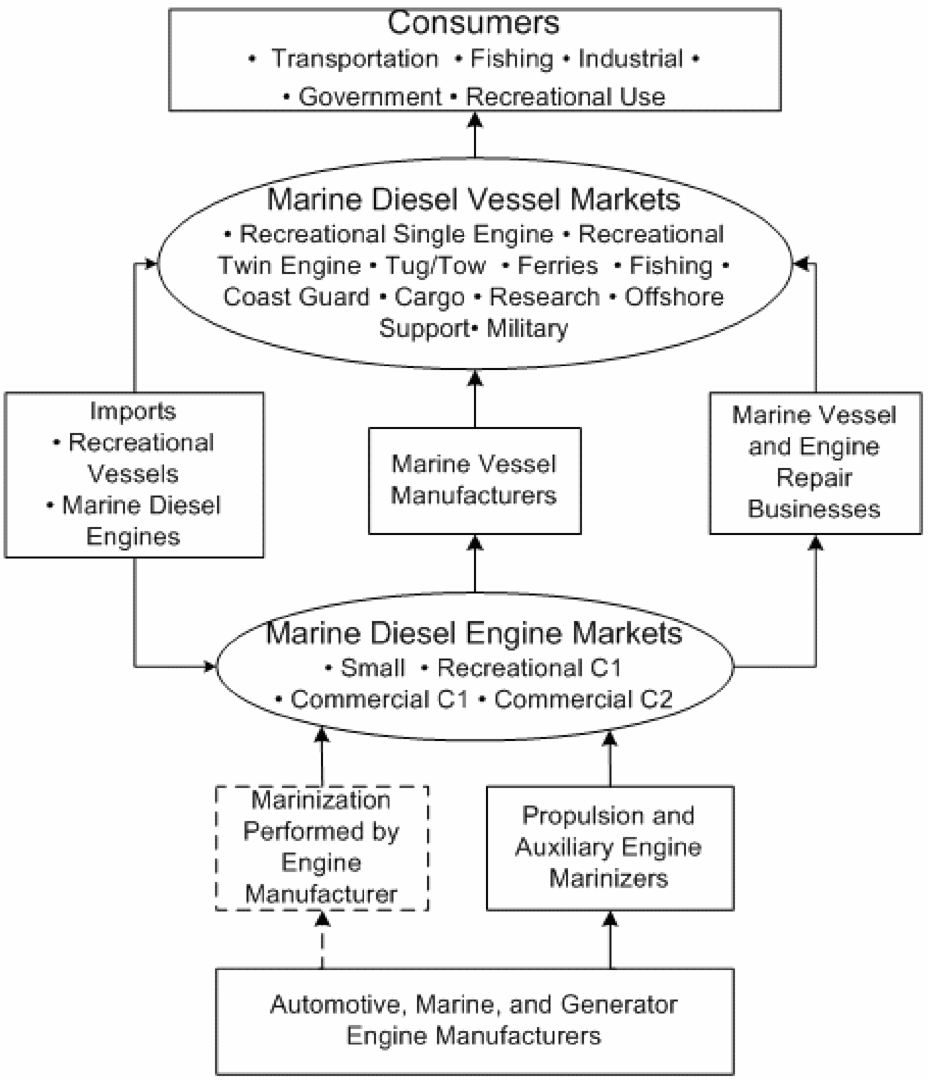
Marine diesel engines include both engines used for propulsion on marine vessels, and those used for marine vessel auxiliary power needs. Diesel marine engines are generally derived from engines originally designed and manufactured for land-based nonroad applications. These nonroad engines are then adapted for use in marine applications through the process of marinization, either by the original engine manufacturer, or by a post-manufacturer marinizer (PMM). The marinization process is discussed in further detail in section 1.1.2.2.2.

Propulsion engines can vary dramatically in size and power, from the smallest engines used in recreational sailboats, to very large engines used in ocean-going commercial vessels. Similarly, auxiliary engines cover a very broad range of sizes and rated power. Auxiliary engines can be used for a variety of purposes, including primary or emergency electrical power generation, and the powering of onboard equipment such as pumps, winches, cable and pipe laying machinery, and dredging equipment. A description of the various engine categories used for regulatory purposes is contained in section 1.1.2.1.

As with marine diesel engines, marine vessels include a very broad range of vessel sizes and types. These include small recreational vessels, as well as commercial vessels such as tow and tug boats, patrol boats, commercial fishing vessels, research vessels, passenger vessels tour boats and ferries), offshore support vessels which service offshore drilling platforms, and a variety of other specialized commercial vessels.

Figure 1-1 shows the links between the various market segments of the marine diesel engine industry and the marine vessel industry, as discussed further in the following sections.

Figure 1-1 Marine Diesel Market Segment Flow Chart



1.1.1.2 Current Emission Regulations

The first standards to take effect for commercial marine diesel engines are the Tier 1 emission standards, which were adopted in 2003, and became effective with the 2004 model year (68 FR 9746, February 28, 2003). These NO_x-only standards apply to commercial marine diesel engines with a per-cylinder displacement of greater than 2.5 liters per cylinder. As shown in Table 1-1 the standards vary depending on the rated speed of the engine.

Table 1-1 Tier 1 Standards for Commercial Marine Diesel Engines over 2.5 Liters per Cylinder

Rated engine speed (rpm)	NO_x (g/kW-hr)
<130	17
130-2000	$45 \times rpm^{-0.2}$
>2000	9.8

We adopted Tier 2 emission standards for Category 1 (C1) marine diesel engines over 37 kW and for Category 2 (C2) marine diesel engines in 1999 (64 FR 73300, December 29, 1999). These standards are shown in Table 1-2.

Table 1-2 Tier 2 Emission Standards for C1 (over 37 kW) and C2 Commercial Marine Diesel Engines.

Category	Displacement (liters/cylinder)	Starting Date	NO_x+THC (g/kW-hr)	PM (g/kW-hr)	CO (g/kW-hr)
1	Power ≥37 kW, disp. <0.9	2005	7.5	0.40	5.0
	0.9 ≤ disp. < 1.2	2004	7.2	0.30	5.0
	1.2 ≤ disp. < 2.5	2004	7.2	0.20	5.0
	2.5 ≤ disp. < 5.0	2007	7.2	0.20	5.0
2	5.0 ≤ disp. < 15.0	2007	7.8	0.27	5.0
	15.0 ≤ disp. < 20.0, and power < 3300 kW	2007	8.7	0.50	5.0
	15.0 ≤ disp. < 20.0, and power ≥ 3300 kW	2007	9.8	0.50	5.0
	20.0 ≤ disp. < 25.0	2007	9.8	0.50	5.0
	25.0 ≤ disp. < 30.0	2007	11.0	0.50	5.0

We applied the Tier 2 emission standards for C1 engines shown in Table 1-2 to recreational marine diesel engines, but with applicable dates two years behind those for the corresponding commercial marine diesel engines (67 FR 68242, November 8, 2002).

There are currently no emission regulations specifically for marine diesel engines less than 37 kW. Rather, these engines are covered by the Tier 2 standards for nonroad compression ignition (CI) engines, as shown in Table 1-3 (63 FR 56968, October 23, 1998).

Table 1-3 Tier 2 Emission Standards for Marine Diesel Engines Below 37 kW

Engine Power	$NMHC+NO_x$ (g/kW-hr)	PM (g/kW-hr)	CO (g/kW-hr)
kW < 8	7.5	0.80	8.0
8 ≤ kW < 19	7.5	0.80	6.6
19 ≤kW < 37	7.5	0.60	5.5

1.1.1.3 Programs in California and Europe

The State of California has recently finalized a requirement that auxiliary engines on ocean-going vessels that operate in California waters use clean distillate fuel. Under California's proposal, NO_x, diesel PM and SO_x emissions from a regulated auxiliary diesel engine would be limited to the emission rates that would have resulted had the engine been fueled with distillate fuel. The regulated auxiliary engines are typically below 30 liters per cylinder displacement, although the California program would also apply to indirect drive diesel engines of any size. The requirements could be met by using either distillate fuel or an alternative emission control strategy as evidenced by an Alternative Compliance Plan. The proposed controls are effective January 1, 2007, for a 5,000 ppm equivalent fuel sulfur limit, and January 1, 2010, for a 1,000 ppm equivalent fuel sulfur limit. The requirements would apply to auxiliary diesel engines on ocean-going vessels while they are operating within any of regulated California waters, which include all California inland waters, all California estuarine waters, and all waters within a zone 24 nautical miles seaward of the coastline.

California's program is roughly patterned after the European Union's marine fuel Directive 2005/33. This directive, which limits the sulfur content of distillate fuels used in EU territory has four components. First, until August 10, 2006, the fuel sulfur content of distillate fuel cannot exceed 2,000 ppm. This applies to DMA, DMB, DMC, and DMX grades.[A] From August 11, 2006 to December 31, 2007, this

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[A] ASTM specifications for marine fuels identify four kinds of marine distillate fuels: DMX, DMA, DMB, and DMC. DMX is a special light distillate intended mainly for use in emergency engines. DMA (also called MGO) is a general purpose marine distillate that must contain no traces of residual fuel. These fuels can be used in all marine diesel engines but are primarily used by Category 1 engines. DMB, also called marine diesel oil, is not typically used with Category 1 engines, but is used for Category 2 and 3 engines. DMB is allowed to have a trace of residual fuel, which can be high in sulfur. DMC is a grade of marine fuel that may contain some residual fuel and is often a residual fuel blend. Residual fuel is typically designated by the prefix RM (e.g., RMA, RMB, etc.). These fuels are also identified by their nominal viscosity (e.g., RMA10, RMG35, etc.). Most residual fuels require treatment by a purifier-clarifier centrifuge system, although RMA and RMB do not require this.

requirement is relaxed for DMB and DMC grades, which are then pegged to the 15,000 ppm SECA limit. That requirement applies to fuels placed on the market during that period. From January 1, 2008 to December 31, 2009, the fuel sulfur limit for DMA and DMX grades falls to 1,000 ppm. Finally, beginning January 1, 2010, a fuel sulfur limit of 1,000 ppm applies to all marine gas oils (DMA, DMB, DMC, and DMX) placed on the market, and to all types of marine fuels used by ships at berth in EU ports and by inland waterway vessels. These last limits apply to any fuel used onboard a vessel. Exemptions apply for ships that spend less than 2 hours at berth, ships that use shore-side electricity while at berth, and hybrid sea-river vessels while they are at sea.

In this proposal we are not considering similar programs for the fuels used by vessels while operating in U.S. territorial waters. We believe that the best approach for addressing emissions from auxiliary engines on foreign vessels that visit US ports is through the adoption of international standards that would reduce both NO_x and PM emissions from these engines. We will continue to participate in discussions for the next tier of international standards at the International Maritime Organization, as part of the U.S. negotiating team. We will also reconsider this issue as part of our future Category 3 marine diesel engine action.

1.1.2 Marine Diesel Engine Manufacturers

Diesel (compression-ignition) engines are designed to be quite robust in order to withstand the very high temperatures and pressures associated with compression-ignition. As a result, they tend to be very reliable and have very long service lives. Their energy efficiency and simple design result in low operating and maintenance costs. As a result, diesel engines tend to dominate commercial marine applications, where cost and reliability are key purchase decisions for the vessel operator. Diesel engines account for only a small portion of the recreational marine market, however, as their initial purchase price is high relative to gasoline (spark-ignition) engines. The benefits of lower operating costs are not nearly as important in the recreational market, where engines tend not to get much use as compared to commercial applications.

The terms "commercial" and "recreational" are defined in 40 CFR Part 94, *Control of Emissions for Marine Compression-Ignition Engines* (Code of Federal Regulations, 2006). The definitions in section 94.2 state that a commercial engine is an engine installed on a commercial vessel. Likewise, a recreational engine is an engine installed on a recreational vessel. Recreational vessel is defined as a vessel that is intended by its manufacturer to be operated primarily for pleasure purposes, although such a vessel could be chartered, rented or leased. Further, a recreational vessel should be less than 100 gross registered tons, should carry fewer than six passengers, and cannot be used solely for competition.

This industry characterization is concerned with the U.S. market for marine diesel engines, which encompasses all diesel marine engines installed on marine vessels to be flagged (registered) in the United States. This includes engines made in the U.S., engines imported for installation in vessels made in the U.S., and engines included in vessels made overseas and imported into the U.S. Unless otherwise noted, the production and engine characteristics data presented in the following sections were obtained from the Power Systems Research OELink database.[2]

1.1.2.1 Engine Categories and Characteristics

For the purposes of this industry characterization, we looked at four broad categories of diesel marine engines, based on the categories that currently exist for emission regulation purposes. These categories are shown in Table 1-4.

Table 1-4 Diesel Marine Engine Categories and Applications

Category	Power	Displacement per Cylinder	Applications
Small	≤37 kW	Any	Auxiliary, Recreational Propulsion
Recreational Category 1	>37 kW	< 5 liters	Recreational Propulsion
Commercial Category 1	>37 kW	< 5 liters	Auxiliary, Commercial Propulsion
Commercial Category 2	>37 kW	≥ 5 liters and < 30 liters	Auxiliary, Commercial Propulsion
Commercial Category 3	>37 kW	≥ 30 liters	Commercial Propulsion

Given the broad range of commercial and recreational marine vessels types, it is difficult to identify typical applications for each engine category. Nonetheless, the following paragraphs provide an overview of the general characteristics and typical applications of engines in each category.

Small: Engines in this category range from 4 to 43 horsepower (hp) and are characterized by low costs and high sales volumes. Most small engines are used for auxiliary purposes on marine vessels or for propulsion on recreational sailboats. In 2002 they accounted for approximately 26 percent of the marine diesel engines produced or imported in the U.S. market. They are typically marinized land-based nonroad diesel engines; we are not aware of any marine engines of this size made solely for marine application.

Category 1 (C1) Recreational: Engines in this category range from 52 to 3,155 hp and are characterized by high power density (power to weight ratio) and low annual hours of operation relative to commercial engines. Such engines are typically operated no more than 200 to 250 hours per year, and often less. These engines are used for propulsion in recreational vessels, which are designed for speed and planing operation. In 2002 they accounted for approximately 34 percent of the marine diesel engines produced or imported in the U.S. market.

Recreational vessels are designed primarily for speed, and this imposes certain constraints on the type of engine they can use. For a marine vessel to reach high speeds, it is necessary to reduce the surface contact between the vessel and the water, and consequently these vessels typically operate in a planing mode. However, the accompanying high engine speeds are sustained for only short periods of time compared to the total operation of the vessel (i.e., long enough for the vessel to get up on plane), and the duty cycle on which these engines are certified reflects these operations.

Planing imposes two important design requirements. First, the vessel needs to have a very high power, but lightweight, engine to achieve the speeds necessary to push the vessel onto the surface of the water. Therefore, recreational engine manufacturers have focused on achieving higher power output with lighter engines (this is also referred to as high power density). The tradeoff is less durability, and recreational engines are warranted for fewer hours of operation than commercial marine engines. The shorter warranty period is not a great concern, however, since recreational vessels, and therefore their engines, are typically used for fewer hours per year than commercial engines, and spend much less time operating at higher engine loads. Second, the vessel needs to be as light as possible, with vertical and horizontal centers of gravity carefully located to allow the hull of the vessel to be lifted onto the surface of the water. Therefore, recreational vessel manufacturers have focused on designing very lightweight hulls. They are typically made out of fiberglass, using precisely designed molds. The tradeoff is a reduced ability to accommodate any changes to the standard design. For these reasons, recreational vessels are typically designed around a specific engine or group of engines, and engines that are heavier or that are physically larger cannot be used without jeopardizing the vessel's planing abilities or, in many cases, designing a new fiberglass mold for a modified hull.

Category 1 (C1) Commercial: Engines in this category are very similar to engines in the C1 recreational category in displacement, but tend to have lower hp ratings than recreational marine diesel engines in order to provide increased durability required in commercial applications. In contrast to C1 recreational engines, C1 commercial engines are typically used 750 to 4,000 hours per year. They are typically used for propulsion in vessels with displacement hull designs. They are also used for a wide variety of auxiliary power needs on marine vessels. In 2002 they accounted for approximately 39 percent of the marine diesel engines produced or imported in the U.S. market.

In contrast to recreational marine vessels, commercial vessels are typically larger displacement hull vessels, and instead of operating on the surface of the water, for speed, they are pushed through the water. The speed at which a displacement vessel can operate is limited by its hull design and above that limit, there are quickly diminishing returns on power: little vessel speed increase is achieved by increasing power. Because vessel speed is limited by the hull design, there is little incentive to over power the vessel, and engines on these types of commercial vessels tend to be lower power when compared to recreational vessels of similar size. Commercial engines operate for long periods at about 80-90% of rated power and are designed primarily with durability and fuel consumption in mind.

Category 2 (C2): Engines in this category are typically derived from engines originally designed for use in locomotives or for land-based stationary power generation. Such engines typically operate 3,000 to 5,000 hours or more per year, and are designed to be durable and have a very long service life. Under our current program, all C2 marine diesel engines are handled the same way; there is no distinction between recreational or commercial engines in this category. In 2002 they accounted for approximately one percent of the marine diesel engines produced or imported in the U.S. market.

As we were developing this proposal, engine manufacturers brought to our attention another category of marine diesel engines that do not fit neatly in the above scheme. These are high power-density marine diesel engines used in some commercial vessels, including certain kinds of crew boats, research vessels, and fishing vessels. Unlike most commercial vessels, these vessels are built for higher speed, planing operation, which allows them to reach research fields, oil platforms, or fishing beds more quickly. These engines may have smaller service lives because of operation at these higher speeds. Our current program does not distinguish between these commercial engines and those used on displacement vessels with respect to useful life periods. Further, this industry characterization does not specifically address these engines as a unique group.

A final category of marine diesel engines, Category 3 (C3) engines, have displacements of 30 liters per cylinder or greater. Such engines are typically only used in large ocean-going vessels, and are not considered in this industry characterization. Table 1-5 shows a summary of the general characteristics of engines in each of the four categories considered in this industry characterization.

Table 1-5 Engine Characteristics for the Considered Engine Categories

	Small	Recreational Category 1	Commercial Category 1	Category 2
Cylinders	1–4	3–16	3–24	5–20
Horsepower	4.2–42.4	52–3,155	37.5–2,500	300–9,190[a]
Engine Speed (rpm)	1,800 – 3,000	1,800 – 3,000	1,800 – 3,000	750 – 1,500
Weight (lbs)	26–246	156–7,491	106–7,900	7,850–35,000
Cycle:				
2	0.0%	10.2%	9.5%	41.0%
4	100.0%	89.8%	90.5%	59.0%
Configuration:				
H-Block	8.1%	0.0%	0.0%	0.0%

Inline	91.9%	65.3%	73.3%	33.7%
V-Block	0.0%	34.7%	26.7%	66.3%
Cooling:				
Air	5.9%	0.0%	0.4%	0.0%
Oil	0.0%	0.0%	0.1%	0.0%
Water	94.1%	100.0%	99.5%	100.0%

a. While the PSR database shows one C2 engine family with a 300 hp rating, C2 engines are generally over 1000 hp at minimum.

Table 1-6 shows the total number of engines in each category which were sold in the United States in 2002.

Table 1-6 Marine Diesel Engine Sales by Engine Category in 2002

Application Category	Sales in 2002	Percent of Total
Small	10,761	26.4%
Recreational C1	13,952	34.2%
Commercial C1	15,826	38.8%
Commercial C2	277	0.7%
Total	40,816	

1.1.2.2 Supply Side

Marine diesel engines are typically derived from land-based nonroad engines. These engines are adapted for use in the marine environment through a process known as marinization. In this section we will discuss nonroad engine design, production and costs, followed by descriptions of the marinization process and the companies engaged in this activity. Finally we will discuss engine dressing and rebuilding practices for marine diesel engines.

1.1.2.2.1 Nonroad Diesel Engine Design and Production

Engine blocks are cast in a foundry, most often from gray iron. Depending on the size and complexity of the engine, the block may be formed by impression molding or two-piece sand-casting. Smaller, more complex parts, including cylinder heads, exhaust manifolds, and cylinder liners, are cast from ductile iron, typically using sand cores to allow formation of the complicated shapes. All castings must be cleaned and deburred prior to further processing. In addition, ductile iron parts will also usually be heat treated to relieve stress and harden the alloys. Table 1-7 lists the materials and primary production processes for various engine components.[3]

Table 1-7 Engine Component Materials and Production Processes

Component	Primary Materials	Primary Process
Block	Iron, aluminum	Casting
Cylinder head	Iron, aluminum	Casting, machining
Intake manifold	Plastic, aluminum	Casting, machining

Connecting rods	Powder metal, steel	Molding, forging, machining
Pistons	Aluminum	Forging, machining
Crankshaft	Iron, steel, powder metal	Molding, forging, machining
Valves	Steel, magnesium	Stamping, machining
Exhaust systems	Stainless steel, aluminum, iron	Extruding, stamping

The cast block, cylinder head, and cylinder liners, along with crankshafts, gears, connecting rods, and other engine parts, are next machined to exact specifications in a machining center. Holes are drilled, parts reshaped, excess metal removed, and the metal surfaces polished in the machining area. The operation of the finished engine depends critically on the precision of the machining work at this stage.

The third major step in engine manufacturing is assembly. This area is usually physically isolated from the dirty upstream operations so that contaminants are not introduced into the completed engines, thus affecting their operation or shortening the engine’s life. In a typical plant, subassemblies are first put together on separate lines or in separate bays; then the subassemblies are brought together for final assembly. The completed engines are visually inspected and then evaluated on-line on a test bench or in a test cell to ensure their performance will meet expectations.

1.1.2.2.2 Engine Marinization

Land-based nonroad diesel engines generally need to be modified in some ways to make them suitable for installation on marine vessels. The process by which this is done is known as marinization. The marinization process results in changes to the emission characteristics of the nonroad engine. For this reason, a marinized nonroad engine must be certified to marine diesel engine emission standards even though the base nonroad engine is certified to the nonroad diesel engine emission standards. Sometimes, land-based nonroad diesel engines can be adapted for use in marine applications without changing the emission characteristics of the engine. This process is called engine dressing, and is discussed in section 1.1.2.2.5. Marinization typically involves three significant modifications: choosing and optimizing the fuel management system, configuring a marine cooling system, and making other peripheral changes. These changes are detailed in the following paragraphs.

Fuel and Air Management: High-performance engines are preferred for most recreational and some light duty commercial applications. These engines are built to maximize their power-to-weight ratio (provide more power with less added weight), which is typically done by increasing power from a given cylinder displacement. This is usually accomplished by installing a new fuel injection system, which injects more fuel directly into the cylinder to increase power. This can require changes to the camshaft, cylinder head, and the injection timing and pressure. Currently, the design limits for increased fuel to the cylinder are smoke and durability. Modifications made to the cooling system also help enhance performance. By cooling the charge, more air can be forced into the cylinder. As a result, more fuel can be injected and burned efficiently because of the increase in available oxygen. In addition, changes are often made to the pistons, cylinder head components, and the lubrication system. For example, aluminum piston skirts can be used to reduce the weight of the pistons. Cylinder head changes include changing valve timing to optimize engine breathing characteristics. Marinizers do not typically go as far as to physically modify the cylinder head.

Cooling System: To mitigate performance problems, engine manufacturers historically used cooling systems that cooled by circulating seawater through the engine that was pumped from outside the boat. Even though many currently operating marine diesel engines still use seawater to cool the engine, almost all newly built engines use a closed cooling system that recirculates coolant through the engine block. These engines still use raw seawater by using it to draw heat out of the engine coolant. These closed systems help prevent corrosion and allow the engine to operate at higher temperatures. As part of the cooling system, water-jacketed exhaust manifolds, pumps, and heat exchangers are added. Marine diesel engines may also have larger oil pans to help keep oil temperatures down.

Other Additions and Modifications: Marine engines are often installed in engine compartments without much air flow for cooling, which can result in a number of exposed hot surfaces (leading to safety concerns) or performance problems from overheating the engine. To address safety concerns and to comply with U.S. Coast Guard regulations, marine diesel engines are designed to keep engine and exhaust component (exhaust manifold, turbocharger and exhaust pipe) temperatures cool. Recreational and light duty commercial engines can accomplish this by running cool water through a jacket around the exhaust system components. Larger engines generally use a thick insulation around the exhaust pipes.

Marinization might also include replacing some engine parts with parts made of materials more durable in a marine environment. These changes include more use of chrome and brass to prevent corrosion. Because of the unique marine engine designs, marinizers also add their own front accessory drive assembly. Finally, marine engines must also be coupled with the lower drive unit to be applicable to a specific vessel.

1.1.2.2.3 Nonroad Diesel Engine Costs of Production

The U.S. Census Bureau does not differentiate cost of production figures for marine diesel engines (North American Industry Classification System [NAICS] 333618B106). However, because small, recreational C1, commercial C1, and commercial C2 engines are derived form nonroad diesel engines, costs of production for nonroad engines could be used to illustrate costs of production of marine diesel engines (NAICS 3336183). Costs of production figures are divided into major input categories of labor, materials, and capital expenditures. Of these categories, purchased materials account for the largest share of total costs. Based on data from the most recent Economic Census, costs of materials represent about 64 percent of the value of shipments, followed by labor at about 11 percent and capital expenditures at about 3 percent. (These numbers correspond with the broader “other engine manufacturing” category [NAICS 333618].)

Table 1-8 lists the primary materials used in engine components.[4] No breakdown of cost of materials used in production is available from the 2002 Economic Census for the specific category of marine diesel engines (NAICS 333618B106) nor for nonroad diesel engines (NAICS 3336183), but based on the broader “other engine manufacturing” category (NAICS 333618), cost of materials are dominated by cast and formed metal. Iron and steel accounted for 13 percent of material costs; aluminum accounted for 7 percent; injection fuel pumps for 5.6 percent; pistons, valves, and piston rings for 3.5 percent; and engine electrical equipment for 3.5 percent. All other materials and components, parts, containers, and supplies accounted for 52 percent; no single material accounted for more than 2 percent of material costs.

Table 1-8 Nonroad and “Other Engine” Costs of Production and Materials Consumed in 2002

NAICS	Value of Shipments ($\$10^6$)	Labor ($\$10^6$)[a]	Cost of Materials ($\$10^6$)[a]	Capital Expenditures ($\$10^6$)[a]
333618 Other engine equipment manufacturing	18,586	2,145	11,800	730
		11.5%	63.5%	3.9%
3336183 Diesel, semi-diesel, and dual-fuel engines (except automobile, highway truck, bus, tank)	2,003	215	1,287	59
		10.7%	64.3%	2.9%
Materials Consumed by 333618	Cost ($\$10^6$)	Share of Cost of Materials		
Iron and steel[b]	1,449	13.1%		
Aluminum[c]	770	6.9%		

a Percentages refer to the share of the total value of shipments.

b NAICS codes 33211101, 33151001, 33120007, 33120016, 33120033.

c NAICS codes 33152005, 33152003, 33631100.

1.1.2.2.4 Nonroad Diesel Engine Manufacturers and Marinizers

As was previously discussed, marine diesel engines are typically derived from similar size land-based diesel engines through the marinization process. Marinization is normally performed by two types of firms, and has an impact on the engine’s emission characteristics.

First, there are large engine manufacturers such as Cummins, Caterpillar, and Deere that marinize their land-based nonroad engines. They are referred to as domestic engine manufacturers (DEMs), and they are usually involved in every step of the manufacturing process of a marine engine. Foreign engine manufacturers (FEMs) are similar to DEM, but they are owned by foreign parent companies (this also pertains to DDC and EMD, which are owned by foreign investment companies now). Production of marine engines begins on the nonroad production line; however, at some stage of the production process, an engine is moved to a different assembly line or area where production is completed using parts and processes specifically designed for marine applications.

Second, postmanufacture marinizers (PMMs), or simply marinizers, are smaller manufacturers that purchase complete or semi-complete land-based engines from engine manufacturers and complete the marinization process themselves using specially designed parts, potentially modifying fuel and cooling systems.

Table 1-9 lists DEM, FEM, and PMM companies. Only four U.S.-based engine manufacturers produce and marinize their marine diesel engines. Cummins is the only company involved in two types of production. In addition to marinizing their own, Cummins (through its subsidiary Onan) produces generators using Kubota engines and therefore is included in both the DEM and postmanufacture marinizers categories.

Table 1-9 Marine Engine Manufacturers

Domestic Engine Manufacturers	Foreign Engine Manufacturers	Postmanufacture Marinizers
Caterpillar	Deutz	Bombardier[a]
Cummins	EQT (parent to DDC)	Brunswick
Deere & Company	Greenbriar Equity, LLC (parent to EMD)	Cummins
General Electric	MAN	Daytona Marine[a]
	Rumo	Fairbanks Morse[a]
	Volvo	Klassen
	Yanmar	Kohler
		Marine Corp. of America[a]
		Marine Power
		NREC Power Systems
		Peninsular Diesel
		Reagan Equipment[a]
		Stewart & Stevenson
		Sword Marine Technology
		Valley Power Systems (parent to Alaska Diesel)
		Westerbeke

a. These companies' production is not included in the 2004 PSR database.

1.1.2.2.5 Marine Engine Dressing

Marine engine dressing refers to the modifications made to a land-based engine that enable it to be installed on a marine vessel. Unlike PMMs, however, the changes made by marine dressers do not affect the emission characteristics of the engine. These modifications can be made by engine manufacturers or marine dressing firms. Modifications typically include installing mounting supports and a generator (in the case of an auxiliary engine) or propeller gears (in the case of propulsion engines). Other modifications consist of adding adaptors, water-cooled exhaust manifolds, water tanks, electronic instrumentation, and alarm systems. There are many manufacturers of this type. However, because these companies do not do anything to the engines to change their emission characteristics, they are exempted from the regulations. Thus, their coverage will be omitted in this profile.

1.1.2.2.6 Marine Engine Rebuilding

Engines are often rebuilt to extend their service life. Engine rebuilding refers to overhauling an engine or otherwise performing extensive renovation on the engine (or on a portion of the engine or engine system). This involves disassembling the engine, inspecting and/or replacing many of the parts, and reassembling the engine in a way that extends its service life. Marine engines are typically rebuilt several times of the course of their service lives.

Many of these marine engine rebuilds are performed by machine shops. The Engine Rebuilders Association lists over 2,500 machine shops in its member database. In 2003, Engine Builder magazine surveyed these machine shops for their 2003 Machine Shop Market Profile. According to their results, 53 percent of these firms were involved in marine engine rebuilding in 2002. The rebuilding of gas and diesel marine engines accounted for 5.1 percent of the total 1.13 million engines rebuilt in 2002.[5] Finally, a large number of engine rebuilds are performed by ship and boat builders at their facilities.

1.1.2.3 Demand Side

Marine diesel engines can be distinguished according to whether they are used on commercial or recreational applications. As discussed above, the basic difference derives from the nature of the requirements on the engine in each application: more power density in recreational applications and more durability in commercial applications. In this section, we look at the characteristics of the four key segments of this industry; Recreational marine C1 and small (at or below 37 kW), Commercial C1, and C2 diesel engine markets.

Table 1-10 Marine Diesel Engine Production by Application and Use Type (2002) presents the total number of engines produced in and imported to the United States broken down by application category. According to the data in the PSR database, the largest single category is marine engines produced for propulsion purposes in recreational applications (17,954). A slightly smaller number was produced for all auxiliary functions (16,377) and the rest for propulsion purposes in commercial applications (6,524). Based on the engine category, the majority of the engines produced or imported were classified as commercial C1, followed by recreational C1 and small. Category 2 is the smallest category with 277 engines produced in 2002.

Table 1-10 Marine Diesel Engine Production by Application and Use Type (2002)

Use Type	Small (≤37 kW)	C1 Recreational	C1 Commercial	C2
Commercial propulsion	NA	NA	6,389	135
Marine auxiliary	6,798	NA	9,437	142
Pleasure propulsion	3,963	13,952	NA	NA
Total	10,761	13,952	15,826	277

1.1.2.3.1 Recreational Applications

Recreational boats (especially the larger ones powered by diesel engines) are generally considered discretionary goods; demand for them is typically price elastic

There are several reasons why consumers might choose diesel engines over gasoline engines for recreational applications. First, diesel engines are more durable and reliable. Second, diesel engines have better fuel consumption.

Based on the National Marine Manufacturers Association (NMMA) sales data, there were approximately 5,760 diesel-powered (out of a total 10,200 diesel and gas-powered inboard cruiser boats) recreational boats sold in 2002. NMMA also estimated that among 10,200 boats, 92.2 percent had a twin engine.[6] Under these ratios, we estimated 11,070 recreational marine diesel engines were sold for propulsion purposes in the United States in 2002. This number differs from 13,952 engines imported or produced in the United States in 2002, as reported in the PSR database. Some of the engines produced are used as the replacement engines; however, the PSR OELink database is probably not entirely accurate. Because the NMMA estimate is derived from surveying a large portion of the industry stakeholders, their consumption estimate seems more reliable.

Not included in that estimate are small marine diesel engines. PSR data indicate that 10,761 small marine diesel engines were produced in 2002, with approximately 64 percent of those being used for auxiliary purposes and the remainder used as maneuvering engines on recreational applications and as cruising engines on sailboats.

1.1.2.3.2 Commercial C1 Applications

Engines in this category are inputs into various commercial applications, such as seasonal and commercial fishing vessels, emergency rescue vessels, ferries, and coastal freighters.

Commercial vessels are inputs into a wide range of production processes that generate products and services. As a result, the demand for C1 engines is linked directly to the demand for boats, and indirectly through the supply chain to the demand for final products and services produced with commercial ships and boats.

No data are readily available on the volumes of commercial boats produced annually in the United States. However, based on the 2004 Workboat Construction survey of approximately 400 commercial boats scheduled to be delivered in 2005, we estimate that 40 percent of them were C1, 55 percent were C2, and 5 percent were C3 (Workboat, 2005). Using these estimates, we find that 160 C1 engine-powered commercial vessels were produced in the United States in 2004. Once again, this number does not correspond with 6,389 engines listed by PSR. More than likely Workboat Construction journal’s survey lists the largest commercial ships and boats, and many smaller commercial boats are unaccounted for.

1.1.2.3.3 Commercial C2 Applications

Commercial C2 engines might be used on crew and supply boats, trawlers, and tug and tow boats. Many of the engines are also used as large auxiliary engines on ocean-going vessels. Based on the Workboat Construction survey estimate, there were 220 C2 engine-powered commercial vessels built in the United States in 2004.[7] This number is lower compared with 2002 production volume (277 engines) listed by PSR.

Like commercial C1 engines, commercial C2 engines are inputs in vessels, which are in turn inputs in production processes that generate products and services. Therefore, demand for commercial C2 engines is linked directly to the demand for commercial C2 vessels and indirectly to the demand for products and services produced with these vessels.

1.1.2.4 Market Structure

Recreational ApplicationsFigure 1-2 and Figure 1-3 present small and recreational C1 marine diesel engine market breakdown by the type of a supplier. In 2002, a majority of the small marine diesel engines (60 percent) were supplied by engine marinizers, with about half of that value supplied by engine dressers, and only 11 percent by FEMs that oversee the entire production process. No DEMs supplied engines to this market. The situation is opposite for the recreational C1 market, where DEMs supply 45 percent of engines, and FEMs supply 26 percent. Marinizers accounted for 28 percent, and dressers for less than 1 percent of the recreational C1 market supply.

Table 1-11 details the top three engine manufacturers and marinizers in the small (at or below 37 kW) and C1 recreational categories. The majority of the engines in the small category are supplied by U.S.-based marinizer Westerbeke (48 percent). In 2002, Japanese manufacturer Yanmar and U.S.-based marinizer Kohler both had approximately 10 percent of the market share. Cummins, a DEM, serves as a marinizer in this market. Kubota engines, marinized by Cummins, accounted for approximately 3.5 percent of small marine diesel engine market supply in 2002.

Figure 1-2 Small (≤37 kW) Marine Diesel Engine Market Supply by Manufacturer Type (2002)

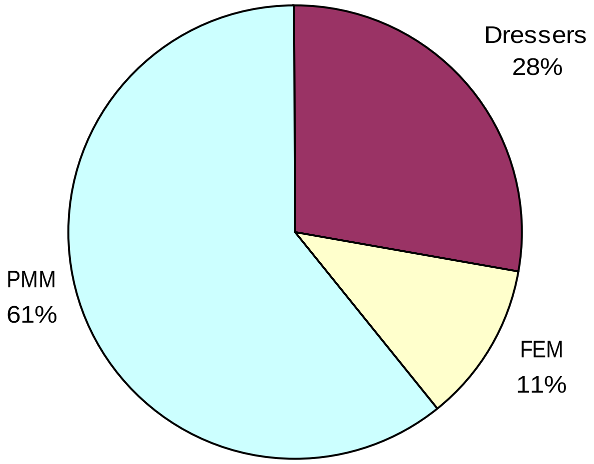


Figure 1-3 C1 Recreational Marine Diesel Engine Market Supply by Manufacturer Type (2002)

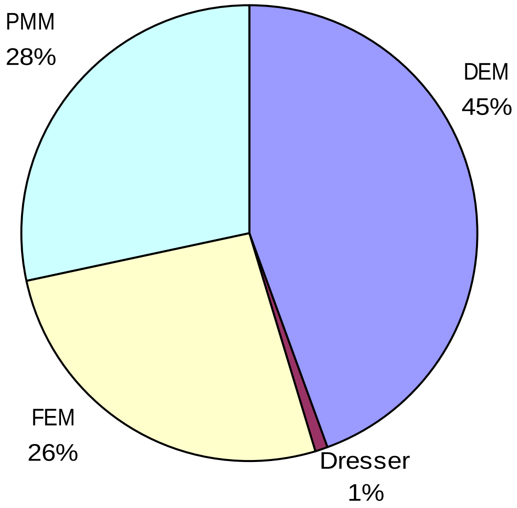


Table 1-11 Top Three Small and Recreational C1 Marine Diesel Engine Manufacturers and Marinizers (2002)

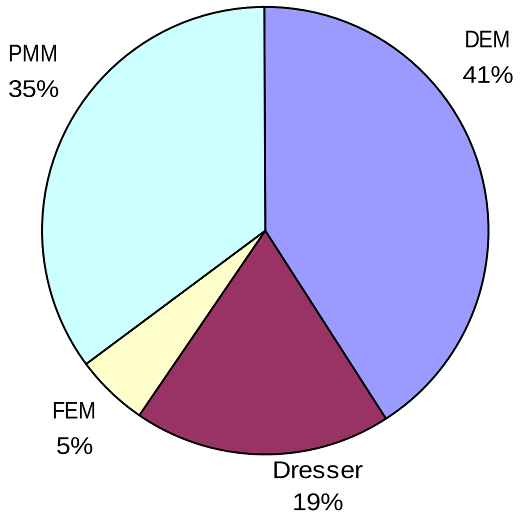
	2002 Production	Market Share
C1		
Engine Manufacturers		
Caterpillar		
Cummins		
Yanmar		
Top 3 Firms’ Production	9,524	68.3%
Engine Marinizers		
Westerbeke		
Peninsular Diesel		
Brunwick Corporation		
Top 3 Firms’ Production	2,800	20.1%
Total Dressers	23	0.2%
Total C1 Market	13,952	
Small (≤37 kW)		
Engine Manufacturers	(D)	(D)
Yanmar		
Engine Marinizers		
Westerbeke		
Valley Power Systems, Inc.		
Kohler		
Top 3 Firms’ Production	7,136	66.3%
Total Dressers	2,000–3,000[a]	25%–30%[a]
Total Small Market	10,761	

a. The range is provided to avoid disclosing proprietary information of individual companies.
(D) = Data have been withheld to avoid disclosing proprietary information of individual companies.

1.1.2.4.1 C1 Commercial Applications

The supply structure of the commercial C1 marine diesel engines market resembles the supply structure of the recreational C1 market, with DEMs and PMMs supplying 76 percent of the engines to the market (Figure 1-4). As opposed to the recreational C1 market, dressers supply a larger portion of the commercial C1 market (19 percent), with FEMs supplying 5 percent.

Figure 1-4 Commercial C1 Marine Diesel Engine Market Supply by Manufacturer Type (2002)



Commercial C1 marine diesel engine market shares are listed by the type of manufacturer in Table 1-12. DEMs Caterpillar and Deere and engine marinizer Kohler have approximately equal market shares of 15 percent each. They are followed by U.S.-based marinizer Westerbeke with an 11 percent market share. Even though engine dressers are not covered by this rule, it is worth noting that the vast majority of the engines supplied in the commercial C1 market by these companies are auxiliary engines.

Table 1-12 Top Three Commercial C1 Marine Diesel Engine Manufacturers and Marinizers (2002)

C1	2002 Production	Market Share
Engine Manufacturers		
Caterpillar		
Deere & Company		
Cummins		
Top 3 Firms' Production	6,452	40.8%
Engine Marinizers		
Kohler		
Westerbeke		
Valley Power Systems, Inc.		
Top 3 Firms' Production	5,690	36.0%
Total Dressers	1,383	8.7%
Total C1 Market	15,826	

1.1.2.4.2 Commercial C2 Applications

The commercial C2 marine diesel market is not supplied by dresser companies; most of the supply comes from marinizers, which supply approximately half of its volume. U.S.-based companies are dominant in the commercial C2 marine diesel engine market. Among engine manufacturers, Caterpillar, and among marinizers, General Motors and Stewart and Stevenson, together compose 78.4 percent of the market. Caterpillar is followed by Japanese manufacturer Yanmar and German MAN B&W with 11 and 6 percent, respectively (Table 1-13).

Table 1-13 Top Three Commercial C2 Marine Diesel Engine Manufacturers and Marinizers (2002)

C2	2002 Production	Market Share
Engine Manufacturers		
Caterpillar	87	
Greenbriar Equity LLC	73	
Yanmar	31	
Top 3 Firms’ Production	191	69.0%
Engine Marinizers		
Stewart and Stevenson	(D)	(D)
Total Dressers	—	0.0%
Total C2 Market	277	

(D) = Data have been withheld to avoid disclosing proprietary information of individual companies.

1.1.2.4.3 Pricing Behavior of Marine Diesel Engine Markets

Discussions about market competitiveness usually focus on two types of pricing behavior: perfect competition (price-taking behavior) and imperfect competition (lack of price-taking behavior). Under the former scenario, buyers and sellers take (and thus are “price takers”) the market price set in a competitive equilibrium: the market price equals the value consumers place on the marginal product, as well as the marginal cost to producers. Under this scenario, firms have some ability to influence the market price of the output they produce. For example, a firm might produce a commodity with unique qualities that differentiate its product from its competitors’ product. The value consumers place on the marginal product, the market price, is greater than the cost to producers. Thus, the social welfare is reduced under this scenario.

As evident from the market share information presented in this report, marine diesel engine markets are moderately (small and commercial C1) to highly (recreational C1 and commercial C2) concentrated and thus have a potential for emergence of imperfect competition. Nevertheless, our analysis suggests mitigating factors will limit prices from rising above the marginal cost; therefore, the assumption of perfect competition is justified.

First, the threat of entry encourages price-taking behavior. Industries with high profits provide incentives to new firms to enter the market and lower the market price to their competitive levels. In all of the marine diesel markets, domestic and foreign candidates can enter any of these markets without incurring significant costs.

Second, the data on capacity utilization rates published by the Federal Reserve (for machinery, NAICS 333) suggest that excess capacity exists in the broad category that also includes converted internal combustion engines industry (NAICS 333618B106). February 2006 data present an industry utilization rate of 82.6 percent. If these data do, in fact, indicate excess capacity in the marine diesel engine industry, then the ability to raise prices is limited by excess idle capacity.

Third, other theories place less value on market shares as a determinant of pricing behavior and examine the role of potential competition instead. For instance, three conditions of perfectly contestable markets demonstrate how potential competition may lead to perfect competition:[8]

- New firms have access to the same production technology, input prices, products, and demand information as existing firms
- All costs associated with entry can be fully recovered
- After learning about new firms' entry, existing firms cannot adjust prices before these new firms supply the market

Although the extent to which these conditions apply to marine diesel engine markets is not clear, the theory suggests that market shares alone should not necessarily be considered as an indicator of imperfect competition in the market.

1.1.2.5 Historical Market Data

1.1.2.5.1 Recreational Applications

The historical market statistics are presented as a means to assess the future of marine diesel engine production. Information on production trends is presented here.

Historical production volumes for recreational C1 and small marine diesel engine markets are presented in Table 1-14. The small marine diesel engine market demonstrated continuous growth in production between 1998 and 2002, growing by 37 percent since 1998. The recreational C1 market experienced a slight peak in 2000 with 7 percent growth and then leveled off in 2002 at a slightly higher volume than it was in 1998.

Table 1-14 Historical Market Trends for Small and Recreational C1 Marine Diesel Markets

	Recreational C1	Small
2002	13,952	10,761
2001	13,754	9,833
2000	14,408	9,576
1999	13,836	7,997
1998	13,446	7,853
Percentage Change	3.8%	37.0%

1.1.2.5.2 Commercial C1 Applications

The commercial C1 engine market demonstrated a strong steady growth in the past 5 years. Starting at 10,508 engines produced and imported into the United States in 1998, it grew by more than 50 percent and equaled 15,826 engines in 2002 (Table 1-15).

Table 1-15 Historical Market Trends Commercial C1 Marine Diesel Market

Year	Production
2002	15,826
2001	14,078
2000	12,838
1999	12,178
1998	10,508
Percent Change	50.6%

1.1.2.5.3 Commercial C2 Applications

The commercial C2 market has a relatively small volume of sales compared to the recreational and commercial C1 markets. Nevertheless, the commercial C2 market experienced significant growth in the past 5 years. In the period from 1998 to 2002, market volume more than doubled and equaled 277 engines in 2002 (Table 1-16).

Table 1-16 Historical Market Trends Commercial C1 Marine Diesel Market

Year	Production
2002	277
2001	231
2000	200
1999	138
1998	134
Percentage Change	106.7%

1.1.3 Marine Vessel Manufacturers

Marine vessels include a wide variety of ships and boats. Several alternative definitions exist to distinguish between ships and boats. For this profile, ships are defined as those marine vessels exceeding 400 feet in length. They are built to purchasers' specifications in specialized "Main Shipyard Base" ship yards, and typically powered by Category 3 diesel engines. Under this definition most of the vessels powered by small, C1 or C2 diesel engines would be considered boats. In this section, the terms "vessel" and "boat" will be used interchangeably. Vessels powered by C1 and C2 engines vary widely; they may be made from fiberglass-reinforced plastic (FRP or fiberglass), aluminum, wood, or steel. Some vessels are serially produced using assembly line methods; others are individually built to meet purchasers' specifications in boatyards or in the same yards that build ships. Small boats may be powered by small spark-ignition (gasoline) engines. Vessels covered by this profile include a small share of recreational boats: inboard cruisers, especially those over 40 feet in length. In addition the profile covers diesel-powered commercial and governmental vessels such as tug/tow boats, fishing vessels, passenger vessels, cargo vessels, offshore service vessels and crew boats, patrol boats, and assorted other commercial vessels.

The Economic Census includes two industry sectors, NAICS 336611 Ship Building and Repairing and NAICS 336612 Boat Building, that together cover the marine vessel types addressed in this profile. Each NAICS includes some vessels not included in this profile. NAICS 336612 defines boats as "watercraft not built in shipyards and typically of the type suitable or intended for personal use."; thus, NAICS 336612 includes essentially recreational vessels; within this NAICS, NAICS 3366123 covers inboard motor boats, including those powered by diesel engines. Thus, the diesel-powered recreational vessels covered by this profile represent only a relatively small share of NAICS 336612. NAICS 336611 comprises establishments primarily engaged in operating a shipyard, fixed facilities with drydocks and fabrication equipment capable of building a "watercraft typically suitable or intended for other than personal or recreational use."[9] Commercial and governmental vessels powered by small, C1 and C2 diesel engines are included in NAICS 336611, along with larger ships that are powered by C3 engines and thus not covered by this profile.

1.1.3.1 Overview of Vessels

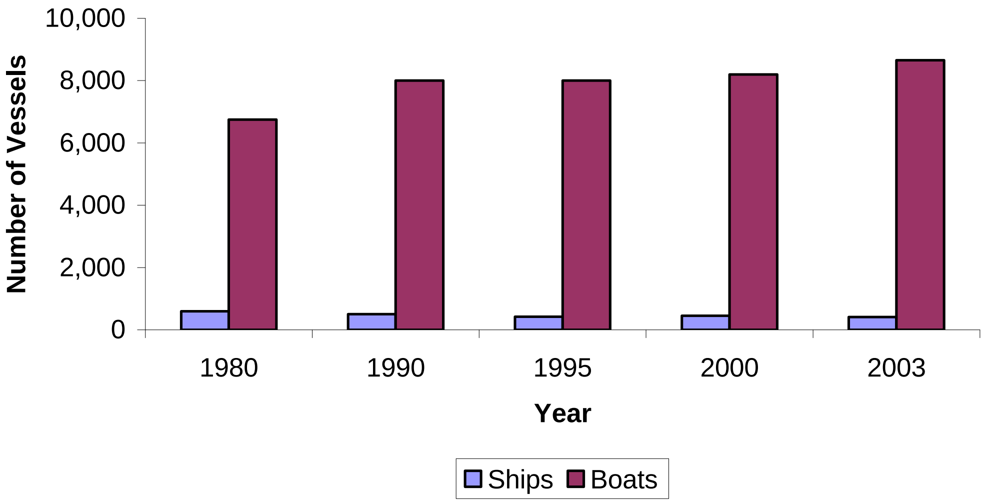
This profile covers a wide variety of vessels, including recreational vessels and smaller commercial, service, and industrial vessels, generally less than 400 feet in length. Commercial vessels under 400 feet long dominate inland and coastal waters where shallow drafts restrict access by larger ships. Depending on their mission, C1- and C2-powered vessels also may operate in the Great Lakes, coastwise, intercoastal, noncontiguous, and/or transoceanic environments. The principal commercial boat types are tugboats, towboats, offshore supply boats, fishing and fisheries vessels, passenger boats, and industrial boats, such as cable- and pipe-laying boats, oceanographic boats, dredges, and drilling boats. Passenger boats include crewboats, excursion boats, and smaller ferries.

Most commercial vessels covered by this profile are U.S.-built, U.S.-owned and U.S.-operated. Under provision of the Jones Act (Section 27, Merchant Marine Act, 1920), vessels transporting merchandise between U.S. ports must be built in and documented under the laws of the United States and owned and operated by persons who are citizens of the United States. Because C1 and C2 diesel engines are frequently used to power vessels that operate in inland waters or coastwise, they are generally operating between U.S. ports. Thus, many cargo vessels powered by C1 and C2 diesel engines are required to be U.S.-built, -owned, and -operated, unless a waiver is granted by the Secretary of the Treasury.

Generally excluded from this profile, because they are powered by C3 engines, are larger merchant and military vessels, typically exceeding 400 feet in length, that engage in waterborne trade and/or passenger transport or military operations. Commercial and government-owned (e.g., military) ships operate in Great Lakes, coastwise, intercoastal, noncontiguous (between United States mainland and its noncontiguous territories, such as Alaska, Hawaii, and Puerto Rico), and/or transoceanic routes. The principal commercial ship types are dry cargo ships, tankers, bulk carriers, and passenger ships. Dry cargo ships include break bulk, container, and roll-on/roll-off vessels. Passenger ships include cruise ships and the largest ferries. Military ships include aircraft carriers, battleships, and destroyers. Also excluded from the profile are the smallest recreational, commercial, and government vessels, which are powered by gasoline outboard, stern-drive, or inboard engines. Figure I-5 illustrates the size of the U.S. commercial fleet over time from 1980 to 2003 and the distribution between larger and smaller vessels. Compared with smaller commercial vessels, larger commercial vessels represent a small fraction of the U.S. commercial fleet.

Figure 1-5 includes vessels as small as 1,000 gross tons in the ship, rather than boat population, and omits key categories of boats (smaller vessels), such as supply boats and fishing boats.[10] It is very difficult to develop useful criteria which will allow the separation of vessels populations into those powered by the various engines categories. Nonetheless, this analysis provides some insight as to the relative proportion of vessel in the U.S. fleet powered by C1/C2 engines versus C3 engines.

Figure 1-5 U.S. Commercial Fleet (1960 to 2003)



1.1.3.2 Overview of Vessel Manufacturers

This report classifies vessel manufacturing facilities ("yards"), according to the types of vessels manufactured. The Economic Census reports on two industry segments that are related to vessel manufacture—shipbuilding and repairing (NAICS 336611) and boatbuilding (NAICS 336612). Shipbuilding facilities typically have drydocks. NAICS 336612 encompasses facilities that build "watercraft suitable for personal or recreational use," which corresponds closely to recreational boats, and NAICS 336611 includes facilities that build larger commercial and government vessels. Both NAICS codes include vessels not covered by this profile.

NAICS 336611 includes generally one-of-a-kind vessels built in a shipyard with drydock facilities, including vessels powered by Category 1 and 2 diesel engines, as well as the larger Category 3 engines. Most vessels manufactured by this NAICS code are for commercial or governmental applications (e.g., Coast Guard, military, Army Corps of Engineers, municipal harbor police).

NAICS 336612 covers generally recreational vessels. These may be built using repetitive methods, such as an assembly line process or individually; it includes those powered by gasoline, alcohol, and diesel engines. Within NAICS 336612, only larger (over 40 feet) inboard cruisers are predominantly powered by diesel engines. This segment of NAICS 336612 (NAICS 3366123 Inboard Motorboats) includes only 82 establishments, less than 7 percent of the total in the NAICS code. Because most of the smaller inboard motorboats are SI-powered, the number of facilities manufacturing diesel-powered recreational vessels is even smaller. The information summarized in Table 1-17 shows information about establishments and companies in NAICS 336611 and 336612, and indicates that there are a large number of small establishments in both of these industry segments.[11] Most companies in both NAICS codes are single-establishment companies.

Table 1-17 2002 Economic Census Data on Shipbuilding and Boatbuilding Industries

	NAICS 336611 (shipbuilding)	NAICS 336612 (boatbuilding)
Number of establishments	639	1,123
Number of companies	586	1,063
Establishments with 100+ employees	91	134
Establishments with 500+ employees	21	16

Within NAICS 336611, the U.S. Maritime Administration (MARAD) classifies yards as either first-tier or second-tier according to building capacity. In the Report on Survey of U.S. Shipbuilding and Repair Facilities, MARAD (2003) identifies 24 first-tier yards, which form the "major shipbuilding base" (MSB) in the United States. The 24 MSB yards satisfy several requirements, including at least one construction position capable of accommodating a vessel that is 400 feet in length or over and an unobstructed waterway leading to open water (i.e., locks, bridges) and the channel water must be a minimum of 12 feet deep. While MSB yards are the only ones to manufacture large ships, many of them also produce smaller commercial vessels. Second-tier yards do not meet these criteria and include many small- and medium-sized yards that construct and repair boats.[12]

1.1.3.3 Recreational Vessels

This section describes the recreational boat manufacturing industry, with special attention to the segment of the industry using diesel engines.

1.1.3.3.1 Types of Recreational Vessels

U.S. boatbuilders construct a variety of recreational boats, including ski/wakeboard boats, powerboats, racing boats, sailboats, recreational fishing boats, and yachts. Only a small segment of recreational boats are powered by diesel engines and thus addressed by this profile. Diesel-powered types of vessels include inboard cruisers and most of the larger yachts.

1.1.3.3.2 Supply of Recreational Vessels

Boats for personal and recreational use can be manufactured from many different materials, including fiberglass-reinforced plastic (FRP), aluminum, rotationally molded (rotomolded) polyethylene or other thermoplastic materials, and wood. Only relatively large (over 40 foot) inboard cruisers commonly use diesel engines; diesel engines used in recreational vessels are almost exclusively C1 engines, although C2 engines may be used on the largest yachts. Among recreational boats, large inboard cruisers are less likely to be serially produced; because they are quite costly, they tend to be customized to buyers' specifications. Like smaller serially produced boats, the most common hull material is FRP.

1.1.3.3.3 Production Process

The most common material used in boat manufacturing is FRP. Boats made from FRP are typically manufactured serially. Using FRP makes it very difficult to incorporate purchaser preferences into a vessel's design because 1) many features are designed into fiberglass molds, making customization time consuming and expensive and 2) vessels constructed from FRP are very sensitive to changes in their vertical or horizontal centers of gravity, making it difficult to change a particular design. In some cases, boat manufacturers produce the FRP hulls and decks used in constructing their boats; in other cases the FRP hulls and decks of boats are manufactured by a contractor for the boat manufacturer.

The process typically used to manufacture these boats is known as open molding. In this process, separate molds are used for the boat hull, deck, and miscellaneous small FRP parts such as fuel tanks, seats, storage lockers, and hatches. The parts are built on or inside the molds using glass roving, cloth, or mat that is saturated with a thermosetting liquid resin such as unsaturated polyester or vinylester resin. The liquid resin is mixed with a catalyst before it is applied to the glass. The catalyzed resin hardens to form a rigid shape consisting of the plastic resin reinforced with glass fibers.

The FRP boat manufacturing process generally follows the following production steps:

- Before each use, the molds are cleaned and polished and then treated with a mold release agent that prevents the part from sticking to the mold

- The open mold is first spray coated with a pigmented polyester resin known as a gel coat that will become the outer surface of the finished part. The gel coat is mixed with a catalyst as it is applied so that it will harden

- After the gel coat has hardened, the inside of the gel coat is coated with a skin coat of polyester resin and short glass fibers and then rolled with a metal or plastic roller to compact the fibers and remove air bubbles. The fibers are applied in the form of a chopped strand mat or chopped roving from a chopper gun; the skin coat is about 90 mils (0.09 inches) thick and is intended to prevent distortion of the gel coat (known as "print through") from the subsequent layers of fiberglass and resin

- After the skin coat has hardened, additional glass reinforcement in the form of chopped roving, chopped strand mat, woven roving, or woven cloth is applied to the inside of the mold and saturated with catalyzed polyester resin. The resin is usually applied with either spray equipment or by hand using a bucket and brush or paint-type roller. The saturated fabric is then rolled with a metal or plastic roller to compact the fibers and remove air bubbles

- More layers of woven glass or glass mat and resin are applied until the part is the desired thickness; the part is then allowed to harden while still in the mold. As the part cures, it generates heat from the exothermic reactions that take place as the resin hardens; very thick parts may be built in stages to allow this heat to dissipate to prevent heat damage to the mold

- After the resin has cured, the part is removed from the mold and the edges are trimmed to the final dimensions

- The different FRP parts of the boat are assembled using small pieces of woven glass or glass mat and resin, adhesives, or mechanical fasteners

- After the assembly of the hull is complete, the electrical and mechanical systems and the engine are installed along with carpeting, seat cushions, and other furnishings and the boat is prepared for shipment

- Some manufacturers paint the topsides of their boats to obtain a superior finish; the larger boats generally also require extensive interior woodwork and cabin furnishings to be installed

As noted above, only the larger inboard cruisers are likely to have diesel propulsion engines. Of all inboard cruisers, 56 percent are diesel-powered. For boats less than 40 feet in length, less than 35 percent are diesel-powered; for those over 40 feet in length, 85 percent are diesel-powered. Table 1-18 provides estimates of inboard cruiser retail sales by engine type and length of boat. In 2003, 5,191 diesel-powered inboard cruisers were sold; of these, 3,032 were 41 feet or longer. Another 988 diesel-powered cruisers ranged from 36 to 40 feet in length. Only 454 were 30 feet long or less.[13]

Table 1-18 Estimates of Inboard Cruiser Retail Unit Sales by Engine Type and Length of Boat

	1997		1999		2001		2003	
Boat Length	Gas	Diesel	Gas	Diesel	Gas	Diesel	Gas	Diesel
30' and under	917	178	1,064	435	1,059	495	279	454
31'–35'	1,525	309	2,199	673	2,458	953	1,294	717
36'–40'	1,048	492	1,142	804	1,280	991	1,984	988
41' and over	529	1,302	428	2,655	420	3,144	572	3,032
Total	4,019	2,281	4,833	4,567	5,217	5,583	4,109	5,191

Table 1-19 summarizes the sales data from 1997 through 2003 for recreational boats. In 2003, an estimated 9,200 inboard cruisers were sold; 97 percent of inboard cruisers over 31 feet long were powered by twin engines. Sales in the United States are expected to continue to decrease as more and more of the larger recreational boats are being built overseas (e.g., Taiwan).[14]

Table 1-19 Estimates of Inboard Cruiser Retail Unit Sales by Single vs. Twin Engine and Length of Boat

	1997		1999		2001		2003	
Boat Length	Single	Twin	Single	Twin	Single	Twin	Single	Twin
30' and under	789	306	1,028	471	1,004	550	463	271
31'–35'	91	1,742	97	2,775	155	3,256	86	1,925
36'–40'	51	1,490	112	1,834	233	2,038	136	2,815
41' and over	30	1,801	23	3,060	32	3,532	20	3,584
Total	961	5,339	1,260	8,140	1,424	9,376	705	8,595

While not all inboard cruisers are diesel-powered, the production costs for inboard cruisers as a group are likely representative of the relative costs of various inputs used in producing diesel-powered inboard cruisers. Production costs for builders of inboard cruisers include the costs of materials, labor, and capital equipment. Materials costs are more than double the cost of labor for these producers and represent roughly half of the value of shipments of inboard cruisers (see Table 1-20).[15] Because diesel engines are generally more expensive than gasoline engines, materials may represent an even larger share of diesel-powered inboard cruiser costs.

Table 1-20 Costs of Production for NAICS 3366123, Inboard Motorboats, Including Commercial and Military, Except Sailboats and Lifeboats

Establishments	Number	Payroll ($1,000)	Number	Hours (1,000)	Wages ($1,000)	Cost of Materials ($1,000)	Capital Expenditures ($1,000)	Value of Shipments ($1,000)
82	13,412	427,949	10,457	20,773	299,815	1,197,464	39,900	2,384,478

1.1.3.3.4 Demand for Recreational Vessels

Recreational boats are final consumer goods, and are generally considered discretionary purchases. Demand for recreational boats is typically characterized by elastic demand.

1.1.3.3.5 Industrial Organization for Recreational Vessel Manufacturers

Recreational boat builders are located along all coasts and major waterways. Table 1-21 provides sales and employment information of recreational diesel boat builders.[16,17,18] Of the 36 companies for which data were identified, only 9 employ more than 500 employees. Two large, multi-facility companies (Genmar and Brunswick) employ 21,000 and 6,000 employees respectively. Companies with fewer than 500 employees would be considered small businesses under the criteria of the Small Business Administration for NAICS 336612. Based on that definition, the majority of firms producing recreational diesel boats would thus be considered small entities.

Table 1-21 Employment Distribution of Companies that Build Recreational Boats

Employment Range	Number of Firms	Revenue Range ($Millions)
0–100	11	1.3 – 8.5
101–250	9	9.2 – 45.0
251–500	7	20.2 – 101.7
501–1,000	4	63.2 – 131.0
1,000+	5	45.60 – 5,229
Total number of firms	36	

Although there are a few large companies in the recreational diesel boat building industry, there are many more small companies. The boat yards are located on water bodies throughout the country, and many serve somewhat regional markets. Because there are a relatively large number of suppliers, because there is increasing competition from foreign suppliers, and because barriers to entry and exit are low, it is reasonable to characterize the markets for recreational diesel vessels as competitive. As described in section 1.1.2.4.3, the potential for competition and entry (contestable markets) forces existing producers to behave in a competitive manner.

1.1.3.3.6 Markets and Trends in the Recreational Vessel Manufacturing Industry

As summarized in Table 1-22, prices for inboard cruisers 41 feet and longer have displayed no clear trend during the period 2001–2003.[19] Prices in most categories dipped in 2003, reaching prices below 2001 levels. This may result from increased competition from foreign suppliers.

Table 1-22 Estimated Average Retail Selling Price of Recreational Inboard Boats by Length of Boat

Boat Length	1997	1998	1999	2000	2001	2002	2003
41' and over	$490,409	$475,869	$469,866	$516,146	—	—	—
41'–49'	—	—	—	—	$449,990	$419,873	$384,329
50'–59'	—	—	—	—	$963,197	$898,256	$842,578
60'–65'	—	—	—	—	$2,166,030	$2,280,029	$2,220,833
66' and over	—	—	—	—	$3,627,189	$4,464,111	$2,816,731

Information from NMMA indicates that the number of larger recreational boats being built abroad, in places like Taiwan, has increased significantly in the last few years. A recent NMMA report on recreational boat sales compiled U.S. Department of Commerce import and export data, as reported in the U.S. International Trade Commission database. The 2003 data confirmed that the trade imbalance continues to grow. Factors affecting this growth include the rising cost of shipping, trade disputes between the U.S. and Europe, and the strength of the dollar, which makes it difficult for U.S. boatbuilders to offer competitive pricing overseas.

Table 1-23 shows that exports of vessels declined from 1997 to 2001, then increased, posting a substantial increase between 2002 and 2003.[20] Imports continue to outpace exports, with the trade balance deficit roughly tripling between 1997 and

2003. However, because of the substantial increase in exports, the deficit actually fell between 2002 and 2003.

Table 1-23 Value of Imported and Exported Vessels (in $Millions)

	1997	1998	1999	2000	2001	2002	2003
Boats export	$678.6	$674.8	$698.5	$662.0	$560.4	$600.5	$746.5
Boats import	$835.0	$874.7	$984.2	$1,074.8	$1,113.1	$1,157.7	$1,207.2
Trade balance	–$156.40	–$199.90	–$285.70	–$412.80	–$552.70	–$557.20	–$460.70

1.1.3.4 Commercial Vessels

This section builds on earlier work by EPA to characterize commercial vessels and identify how many of each type are powered by C1 and C2 diesel engines. U.S. boatbuilders construct a wide variety of commercial vessels. Most of these boatbuilders are single-establishment companies and manufacture a limited number of boat designs. A handful of yards (e.g., Halter Marine) also have the capacity to build ships that would be powered by C3 engines. Most commercial and government boats are manufactured individually or customized to purchaser’s specifications.

U.S. boatyards build boats primarily used on inland and coastal waterways between U.S. ports. Cargo vessels on these routes must satisfy Jones Act requirements and, therefore, be built in the United States (U.S. Department of Transportation, 1998). As described above, the Jones Act (Section 27 of the Merchant Marine Act of 1920) requires that any vessel transporting merchandise between U.S. ports be built in the U.S., owned and operated by U.S. citizens. For this reason, the U.S. commercial boatbuilding industry has a protected local market and does not face the intense foreign competition that recreational boat builders or shipbuilders building vessels for international trade do. Clients include American waterways operators (e.g., tugboats), offshore petroleum exploration and drilling companies (e.g., liftboats, crewboats, supply boats), fisheries companies (e.g., fishing and fish processing boats), industrial companies, (e.g., cable-laying boats), and research organizations (e.g., oceanographic research vessels).

The markets for commercial and governmental vessels can be modeled as if they were competitive. While the Jones Act prohibits foreign manufacture of cargo vessels trading between U.S. ports and the Passenger Services Act imposes a fee of $200 per passenger on carriers transporting passengers between U.S. ports unless the vessels are U.S.-built, -owned, and -operated, most markets for commercial vessels have relatively low barriers to entry and exit. There are a significant number of firms in each market segment, and they compete for both government and commercial contracts.

For the commercial boat market, we collected much of the background information in a separate report.[21] Although the objective of that report was to develop inputs for emissions inventory modeling, the report provides a general characterization of commercial vessels, and estimates both C1 and C2 vessel counts of some types. This report adopts the same commercial/governmental vessel categories and definitions.

1.1.3.4.1 Tug and Towboats

Towboats, also known as tugboats, include boats with rounded bows used for pulling (towboats) and boats with square bows for pushing barges, known as pushboats. Towboats that pull or push barges are referred to as line-haul boats, and are the largest category of towboats. Specialized towboats may also be used for maneuvering ships in harbors, channel dredging, and construction activities. Towboats vary widely in size and configuration, ranging from small harbor tugs less than 30 feet in length to large ocean-going tugs over 100 feet.

Data from WorkBoat Magazine's annual construction survey are shown in Table 1-24.[22] Participating in this survey is voluntary, and only 56 of more than 500 companies that build commercial boats and ships responded. The voluntary nature of the survey may result in some selection bias such that the respondents are not fully representative of the nonrespondents. This effect may be relatively stable over time, however, so that trends in the data may be indicative of trends in the industry as a whole.

Table 1-24 shows that the number of towboats (including towboats, pushboats, tugs, and AHTS) in production increased from 39 in 2003 to 57 in 2004, and 73 in 2005. The Category 2 Vessel Census[23] estimated that 3,164 of 4,337 towboats in existing databases had C1 engines. Thus, it is likely that the majority of the newbuilt towboats are also powered by C1 engines. According to the Vessel Census, the majority of these towboats operate in the Gulf Inland and Inland areas.

Table 1-24 U.S. Commercial Boat Orders, 1993, 1994, 1997 and 2003, 2004, 2005

	Number of Boats Produced					
Vessel Type	1993	1994	1997	2003	2004	2005
Number of survey respondents	85	83	84	40	46	56
Casino/gaming	34	27	6			
Passenger (dive, dinner, excursion, ferries, sightseeing, water taxi, charter)	102	95	68	44	31	40
Crew, crew/supply pilot, personnel launch	27[a]	41	44	17	31	18
Supply/service		5	81	37	25	29
Liftboat, utility	26[b]		34	5	7	8
Pushboat, towboat, tug	28	60	88[c]	39	57	73
Fire, rescue		5	7	2	12	2
Boom, spill response	60	33	38	4	10	6
Small craft (assorted), tender	44[d]	124[e]	38	17	7	14
Patrol (military, nonmilitary)	99[f]	89	48	74	69	92
Other military			79	27	6	24
Others	26	33	38	110[g]	149	155

	Number of Boats Produced					
Total number of boats	446	512[h]	569	376	405	460

a Supply boats were consolidated with crew/supply boats and pilot boats.
b General workboats were consolidated with utility boats in the 1993 survey.
c AHTSs were consolidated with pushboats, towboats, and tugs.
d Research and survey boats were consolidated with tenders in the.1993 survey and in the table for 2004 and 2005.
e Research, survey, and utility boats were consolidated with the assorted small craft and tenders in the 1994 survey.
f Fireboats were consolidated with the patrol boats in the 1993 survey.
g The total number of "other" boats in included nonself-propelled vessels (2003–42 vessels, 2004–92 vessels, 2005–80 vessels).
h The total number of boats in 1994 did not include the 111 RIBS, skiffs, or small utility, or the 26 support, minehunter, or landing craft reported.

1.1.3.4.1.1 Supply of Tugs and Towboats

The majority of towboats are manufactured individually according to buyer specifications. Some of the smallest ones may be serially produced. Towboats are strongly built and have relatively large engines for their dimensions. All but the very smallest tugs and towboats are made of steel.

Shipyards and boatyards building commercial ships including towboats use a variety of manufacturing processes, including assembly, metal finishing operations, welding, abrasive blasting, painting, and the use of engines for crane operation and boilers. The typical ship construction process begins with steel plate material. The steel is formed into shapes, abrasively cleaned (blasted), and then coated with a preconstruction primer for corrosion protection. This is typically done indoors at the bigger shipyards and most facilities have automated these steps. Using the preformed steel plates, small subassemblies are then constructed and again a primer coat is applied. Larger subassemblies are similarly put together and primed to protect the steel substrate material. At some point in the construction, components are moved outdoors to work areas adjacent to the drydock. Final assembly and engine installation are done at the drydock.

Based on statistics for the shipbuilding NAICS code, NAICS 336611, materials account for more than 50 percent of the cost of production, and labor for approximately 40 percent. Energy costs, investment in capital equipment, rental payments, and business services all account for smaller shares of total value of shipments.

1.1.3.4.1.2 Demand for Tugs and Towboats

Towboats are purchased by towing companies that move cargo on barges on coastal routes or on the nation's rivers. According to the American Waterways Operators, the tugboat, towboat, and barge industry include more than 4000 operating tugs/towboats and more than 27,000 barges. These vessels move more than 800 million tons of raw materials and finished goods each year, including more than 20 percent of the nation's coal, more than 60 percent of the nation's grain exports, and most of New England's home heating oil and gasoline.[24] In addition to commodity transportation, tugs are needed within harbors to maneuver ships to and from their berths, and to assist with bunkering and lightering. The demand for towboats is thus derived from the demand for commodity transportation services, which in turn is derived from the demand for the commodities being transported.

1.1.3.4.2 Commercial Fishing Vessels

Commercial fishing vessels are self-propelled vessels dedicated to procuring fish for market. Commercial fishing boats may be distinguished by whether they tow nets or are engaged in "hook and line" fishing, or are multipurpose vessels that support a variety of fishing activities. Fishing vessels vary widely in size and configuration. Smaller fishing vessels may be serially produced using fiberglass, similar to recreational boats. Larger fishing vessels are generally built individually to buyer's specifications. The largest fishing vessels also serve as factory ships with the capacity to sort, clean, gut, and freeze large quantities of fish.

The Vessel Census, based on the Coast Guard's Merchant Vessels of the U. S. (MVUS) database, estimates that there are more than 30,000 commercial fishing vessels operating in the U.S., with the largest number being in Alaska, followed by Washington and Texas. Other states with large numbers of commercial fishing vessels include California, Florida, Louisiana, and Maine. Of the roughly 30,000 commercial fishing vessels identified, 8,130 are listed as definitely C1 and another 21,300 are characterized by the report's authors as probably C1. If accurate, this means that all but 700 or so commercial fishing vessels are powered by C1 engines, and that the remaining 700 are powered by C2 engines. The C2 vessel census[25] suggests that the actual number of C2 powered fishing vessels may be less than half this number. Less than 1 percent of commercial fishing vessels were identified as gasoline-powered.

Given that the vast majority of commercial fishing vessels are powered by C1 engines, it seems reasonable to assume that the majority of these vessels are also similar to recreational vessels in construction. Small commercial fishing vessels must be able to travel rapidly to and from fishing grounds given that their operations have them going to fishing grounds and returning to port each day. Thus, many of these vessels have fiberglass hulls and are designed for planning operation, much like recreational vessels.

1.1.3.4.2.1 Supply of Commercial Fishing Vessels

Smaller commercial fishing vessels are generally produced using fiberglass with a production method similar to that used for recreational boats. Mid-size fishing boats may be made of fiberglass, aluminum, or steel, and are likely produced individually to buyers' specifications. The largest fishing boats, factory ships, are produced individually at shipyards and a few exceed the 400 foot length that is covered by this profile. Serial and individual production methods are described above.

1.1.3.4.2.2 Demand for Commercial Fishing Vessels

Commercial fishing boats are inputs into the production of fish for sale to consumers, restaurants, retailers, and processors. Reduced catch in many of the nations' fisheries has resulted in lower returns for fishermen, and thus in a declining number of commercial fisherman and declining demand for commercial fishing vessels. This decline is projected to continue.[26] To the extent that governmental efforts to replenish stocks and increase catch are successful, some increase in the number of commercial fishermen and fishing boats may occur in the future.

1.1.3.4.3 Patrol Vessels

Patrol boats such as Coast Guard vessels (government, Department of Homeland Security), include small boats used by harbor police and other patrols and larger vessels such as cutters. Small boats used by the Coast Guard include approximately 1,400 boats ranging from 12 to 64 feet, which operate close to shore. Coast Guard cutters are at least 65 feet in length, and range up to more than 400 feet in length. The Vessel Census identified 158 of 235 cutters that were powered by C2 engines. The smaller boats operated by the Coast Guard were determined to be powered by C1 engines. Fast pursuit boats may be powered by gasoline engines. The majority of patrol boats not operated by the Coast Guard are relatively small and thus most likely powered by C1 engines, or SI outboards for the smallest patrol boats.

1.1.3.4.3.1 Supply of Patrol Boats

Patrol boats are generally manufactured from aluminum (two major manufacturers of patrol boats, Seaark Marine and SAFE Boats, Inc., both manufacture aluminum boats in large numbers). Other aluminum boatbuilders with government work, including military as well as state and local agencies, include Kvichak Marine, Northwind Marine, Rozema, All American Marine, ACB, Almar, Munson and Workskiff. While their designs can be customized, these aluminum boats are largely serially produced. Significant inputs include aluminum, engines, and labor. Some small patrol boats are inflatable, with reinforced rigid hulls made of steel. Larger patrol boats such as Coast Guard cutters are made of steel.

1.1.3.4.3.2 Demand for Patrol Boats

Government agencies, including the Coast Guard, the Military, the Army Corps of Engineers, as well as harbor police and municipalities are the major demanders of patrol boats. The need to increase vigilance along our coasts and in our harbors since the September 11 attacks has led to a tremendous increase in demand for Coast Guard patrol boats, which is likely to continue to be strong for several more years as the fleet is built up.[27] The Workboat Construction Survey shows that contracts have risen from 48 in 1997 to 92 in 2005.

1.1.3.4.4 Passenger Vessels

Passenger vessels powered by C1 or C2 diesel engines include ferries, excursion boats, and water taxis. Ferries are self-propelled vessels that carry passengers from one location to another, either with or without their automobiles. Ferries may be owned by states or private companies, and generally operate over set routes according to regular schedules. Water taxis are generally smaller than ferries and operate on a for-hire basis. The Vessel Census studied ferries, and identified 106 that were powered by C2 engines and 508 powered by C1 engines. Water taxis are generally powered by SI engines, although some may be powered by C1 inboard engines. Excursion boats are generally powered by C1 engines, although some of the larger ones that approach small cruise ships in size, are powered by C2 engines.

1.1.3.4.4.1 Supply of Passenger Vessels

Passenger vessels may be made of aluminum or steel. For example, Derektor Shipyards had orders to deliver three aluminum ferries ranging from a 92 foot high speed catamaran ferry to a passenger/vehicle ferry that was 239 feet long. Two other companies had orders for large steel ferries, including two 310-foot Staten Island Ferries. Larger ferries and other passenger vessels are likely powered by C2 engines, while smaller ones are likely C1 or even SI outboard or sterndrive for the smallest and lightest ones.

1.1.3.4.4.2 Demand for Passenger Vessels

Ferries and water taxis are needed for transportation services, and are generally used in urban areas. Other types of passenger vessels, including excursion boats, dinner boats, and floating casinos, are needed for recreational purposes. Some of these, such as whale watching boats, are very small; others such as floating casinos and some excursion boats may be more than 100 feet in length. Workboat's 2005 Construction Survey showed orders for 19 dinner, excursion, or sightseeing boats and also for 19 ferries or water taxis. Both types of passenger boats are likely to respond to cyclical patterns in the economy, as both commuting and recreation increase when the economy is strong.

1.1.3.4.5 Research Vessels

Research vessels include vessels equipped with scientific monitoring equipment used to track wildlife, map geological formations, monitor coastal water quality, measure meteorological conditions, and conduct other scientific investigations. They vary widely in size and complexity and may be made of aluminum, fiberglass, or steel. They may be powered by SI outboard engines, C1, or C2 inboard engines, depending on their size. While they may be built on a standard hull design, the fittings are highly individualized based on their task, and may be technically complex. Of 12 research vessels reported in the Workboat 2005 Construction Survey, most are made of aluminum and are less than 80 feet in length. Two are made of steel and are about 150 to 200 feet in length. Of the purchasers listed, three of the vessels were ordered by the National Oceanic and Atmospheric Administration (NOAA) and one by a university. The instruments and other scientific equipment are a special and potentially expensive cost element for these vessels. Demand for the vessels is a function of demand for the research products that they support.

1.1.3.4.6 Offshore Support Vessels

Offshore support vessels include a variety of vessels used to construct, operate, maintain, and service offshore oil platforms. Of the categories listed in Table 1-24, crew, crew/supply, personnel, supply/service and liftboat/utility vessels are all vessel types that support the offshore oil industry. This is a heterogeneous category, including a wide range of sizes, materials, and configurations. Platform supply boats and crew/supply boats tend to be over 150 feet in length and may be made of steel or aluminum. Lift boats tend to be about 150 feet in length and made of steel. OSVs listed in Workboat’s 2005 Construction Survey range from 145 feet to 280 feet and are made of steel. At the other end of the spectrum are smaller aluminum crew and utility boats. Most offshore oil activity in the U.S. is in the Gulf of Mexico; thus, most offshore support vessels operate there.

Demand for offshore support vessels depends largely on the status of the offshore oil industry. Changes in that industry over the past 15 years have resulted in reduced numbers of rigs, but some much farther from shore. Thus, while fewer support vessels may be needed, they may be required to be larger and more seaworthy. The Gulf Coast hurricanes of 2005 had a substantial impact on the offshore oil industry and offshore support vessels. Many platforms and offshore support vessels suffered damage due to the storms. Demand for offshore support vessels increased drastically, and day rates more than doubled. This will likely result in an increase in construction of offshore support vessels in the next few years, relative to recent years.

Table 1-25 gives a summary of the types of boats currently under contract to be built at U.S. boatyards based on information taken from the Marine Log website and Workboat’s 2005 Construction Survey, using the commercial boat categories described above.[28]

Table 1-25 Boats Under Construction by Type and Client, December 2005 Contracts

Type of Boat	Commercial Clients	Government Clients	Total
Tow/Tug	31	7	38
Fishing	0	1	1
Coast Guard	0	92	92
Ferry	19	2	21
Cargo	75	0	75
Research	1	2	3
Offshore Support	31	0	31
Great Lake/Others	3	1	4

Military	0	64	64
Total	140	169	329

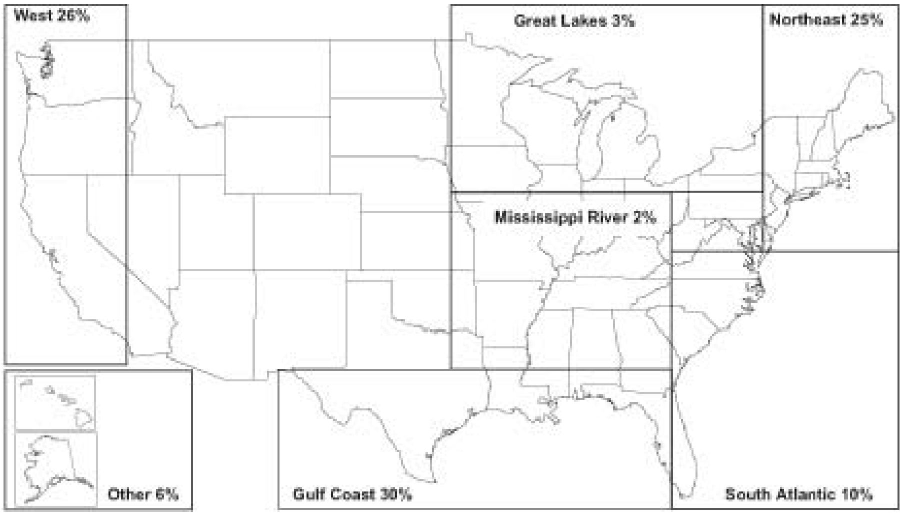
1.1.3.5 Industry Organization

This section examines the organization of the boat building industry, including characterizing firms in the industry, and examining market structure.

1.1.3.5.1 Location and Number of Vessel Manufacturers

There are several hundred yards that build many different types of boats powered with small (≤37 kW), C1 and C2 engines. Boatbuilders are located along all coasts and major inland waterways of the United States. Figure 1-6 shows the geographic distribution of boatbuilders in the United States. A majority of these boatbuilders are located in the Gulf Coast, the Northeast, and the West Coast. The number of boatbuilders in these three regions account for approximately 30 percent, 25 percent, and 26 percent of the boatbuilding industry, respectively. A majority of boatbuilders are located in the Gulf Coast (128), the Northeast (107), and the West Coast (110). Collectively, these three regions represent 345 boatbuilders, or 80 percent of all companies in the 1998 Boatbuilder Database.

Figure 1-6 Major Boatbuilding Regions of the United States



1.1.3.5.2 Firm Characteristics

Table 1-26 summarizes company financial data for companies that produce commercial vessels powered by C1 and C2 engines.[29,30,31] The available data capture total company employment and sales figures including any subsidiaries and operations, such as boat repair, that may not be related to boatbuilding; similarly, because many companies may produce boats powered by both SI and CI engines, or may produce larger vessels powered by C3 engines, not all of the boatbuilding employment and revenues are related to vessels powered by C1 and C2 engines.

Table 1-26 Employment Distribution of Companies that Build Commercial and Government Boats

Employment Range	Number of Firms	Revenue Range ($Millions)
100 or fewer	29	0.15 – 7.0
101–250	12	12.0 – 50.0
251–500	5	11.0 – 30.9
501–1,000	3	42.0 – 73.0
1,001 or more	13	82.0 – 29.9
Total number of firms	62	

Almost all companies that produce commercial or governmental vessels powered by C1 or C2 engines would be classified under NAICS 336611. Of an estimated 589 firms in that NAICS code, company names, employment, and sales data were obtained for only 62. Using the Small Business Administration's small business criterion for NAICS 336611 (1,000 employees), 49 of the 62 (79 percent) of the companies for which data were obtained would qualify as small entities.

1.1.3.5.3 Markets and Trends in Commercial Vessel Manufacturing

Markets for commercial and governmental vessels can be modeled as competitive. While products are differentiated rather than homogeneous, there are many yards that produce similar types of vessels, and compete for both commercial and governmental contracts. Barriers to entry and exit are relatively low, at least domestically. For commercial cargo vessels working between U.S. ports, foreign competition is limited by the Jones Act. Similarly, passenger vessels plying exclusively domestic routes are constrained by the U.S. Passenger Services Act. Nevertheless, because the technology and materials for boat building are widely available, costs of entry into the market are fully recoverable, and barriers to entry and exit are thus low, domestic commercial boat manufacturers face markets that are contestable and therefore behave as if the markets were competitive.

The U.S. boatbuilding industry is currently influenced by several key factors. These factors suggest a continued increase in the number of commercial boats built in the United States:

- Increasing demand for the T-class vessels. (The U.S. Coast Guard defines T-class boats as boats not designed to see the open ocean, such as cruise boats, dinner and gambling boats, crew boats in the Gulf of Mexico, and off-shore vessels)

- Increasing demand for offshore supply vessels to repair and service offshore oil rigs, including repairing or replacing rigs and OSVs damaged or destroyed by Gulf Coast hurricanes in 2005

- Increasing demand for oil (e.g., drillships and semisubmersible rigs)

- Expansion in casino boats

- Decisions by leading boatbuilders to reopen facilities and expand their labor forces are strong indications that they anticipate continued growth in the market for commercial and governmental vessels. An increase in demand for new boats will mean more business for the commercial U.S. boatbuilding industry, as foreign builders are ineligible to build for segments of this market. Some of the larger boatbuilders in the United States also build boats for foreign owners/operators, particularly for foreign militaries. As noted in the table summarizing current shipyard/boatyard contracts, there are at least three yards doing work with foreign governments (e.g., Egypt and Oman)

In summary, U.S. boatbuilders are cautiously optimistic about the future because almost every segment of the U.S. flag fleet is facing significant replacement requirements. The commercial boatbuilders are expected to continue to be a major consumer of marine diesel engines.

1.2 Locomotive

The regulations for locomotives and locomotive engines are expected to directly impact three industries. These industries are: (1) locomotive and locomotive engine original equipment manufacturers (OEMs); (2) owners and operators of locomotives (railroads); and (3) remanufacturers of locomotives and locomotive engines including OEMs, railroads, and independent remanufacturers. Locomotive manufacturers are companies that make or import complete “freshly” manufactured locomotives[B].

Remanufacturers are companies that certify kits for remanufactured locomotives.[C] A brief overview of these industries follows, along with descriptions of the national economic impact of railroads and current regulations in effect for railroads.

[B] Freshly manufactured locomotives are those which are powered by freshly manufactured engines, and contain fewer than 25 percent previously used parts (weighted by the dollar value of the parts).

[C] Remanufactured locomotives are locomotives in which all of the power assemblies are replaced with freshly manufactured (containing no previously used parts) or refurbished power assemblies. Remanufacturing includes the following: replacing an engine, upgrading an engine, and converting an engine to enable it to operate using a fuel other than it was originally manufactured to use.

1.2.1 Current Emission Regulations

The Agency's 1998 Locomotive Rule (63 FR 18978; April 16, 1998) created a comprehensive program that both the large Class I and small Class II and III railroads were subject to, including emission standards, test procedures and a full compliance program. The unique feature of this program was the regulation of the engine remanufacturing process, including the remanufacture of locomotives originally manufactured prior to the effective date of that rulemaking. Regulation of the remanufacturing process was critical because locomotives are generally remanufactured four to eight times during their total service lives of approximately 40+ years. Electric locomotives, historic steam-powered locomotives, and locomotives freshly manufactured prior to 1973 were not covered by the 1998 regulations.

Several requirements are currently applicable to Class I railroads. First, railroads purchasing a new locomotive must insure it meets the current standards and has a valid certificate of conformity. Second, with regard to in-use testing, railroads must reasonably supply locomotives to the locomotive engine manufacturers for purposes of testing them under the manufacturer in-use testing program. In cases where the railroads fail to meet this requirement EPA could, under section 114 of the Act, require the railroads to perform the testing itself. Third, the railroads must also comply with the in-use testing requirements of the post-useful life railroad in-use testing program. Fourth, failure of a railroad to perform all proper maintenance on certified locomotives, so they continue to meet the applicable emissions standards, are subject to civil penalties for tampering. Railroads must also keep records of this maintenance. Finally, when remanufacturing all 1973 and later locomotives, railroads must remanufacture to new standards. (Note: small railroads are generally exempt from these provisions.)

Small railroads have three requirements under the existing emission regulations. First, small railroads are subject to the prohibition against remanufacturing their locomotives without a valid certificate of conformity. However, the regulations exempted their existing noncompliant locomotives as well as any noncompliant locomotives that they purchase from other railroads in the future. The prohibition only applies to previously certified locomotives. For example, if a Class I railroad had a 1990 locomotive that was remanufactured in 2005 to meet the Tier 0 standards, any small railroad that purchased that locomotive would need to comply with the Tier 0 requirements for all subsequent remanufacturing. Second, small railroads must properly maintain (with respect to emissions) all certified locomotives, and they must keep records of this maintenance. Finally, if any small railroad purchased a totally new locomotive, they would need to ensure that it meets the current standards and has a valid certificate of conformity.

Three separate sets of emission standards (Tiers) have been adopted, with applicability of the standards dependent on the date a locomotive is manufactured. The first set of standards (Tier 0) applies to locomotives and locomotive engines originally manufactured from 1973 through 2001. The second set of standards (Tier

1) applies to locomotives and locomotive engines originally manufactured from 2002 to 2004, and the final set of standards (Tier 2) applies to locomotives and locomotive engines originally manufactured in 2005 or later. All of these standards must be met when a locomotive is "freshly manufactured" and at each subsequent remanufacture. The emission standards set in 1998 for Class I and large Class II and II line-haul and switch duty-cycles are shown in Table 1-27.

Table 1-27 Maximum Permissible NO_x, CO, HC, and PM Rates by Tier

(g/bhp/hr)	Tier 0 Line-Haul Duty-Cycle	Tier 0 Switch Duty-Cycle	Tier 1 Line-Haul Duty-Cycle	Tier 1 Switch Duty-Cycle	Tier 2 Line-Haul Duty-Cycle	Tier 2 Switch Duty-Cycle
NO_x	9.5	14.0	7.4	11.0	5.5	8.1
CO	5.0	8.0	2.2	2.5	1.5	2.4
HC	1.00	2.10	0.55	1.20	0.30	0.60
PM	0.60	0.72	0.45	0.54	0.20	0.24

1.2.1.1 Certification

Locomotive manufacturers must produce compliant locomotives, and they must be certified. In order for a locomotive to be certified, a company must certify the engine together with the locomotive. An engine manufacturer can certify, but it must certify the complete locomotive. Currently, engine manufacturers have only certified locomotives they manufactured themselves. Class I and all Class II and III railroads must purchase all new locomotives with a valid certificate of conformity, and when remanufacturing a locomotive must have a valid certificate of conformity. Small Class II and III railroads are, however, provided an exemption for their existing noncompliant locomotives as well as any noncompliant locomotives that they purchase from other railroads in the future.

1.2.2 Supply: Locomotive Manufacturing and Remanufacturing

1.2.2.1 Locomotive Manufacturing

1.2.2.1.1 Types of Locomotives

Locomotives generally fall into three broad categories based on their intended use: switcher, passenger, and line-haul locomotives. Switch locomotives, typically 2000 hp or less, are the least powerful locomotives, and are used in freight yards to assemble and disassemble trains, or for short hauls of small trains. Some larger road switchers can be rated as high as 2300 hp. Passenger locomotives are powered by engines of approximately 3000 hp, with high-speed electric passenger locomotives powered by 6000hp or more. Freight or line-haul locomotives are the most powerful locomotives and are used to power freight train operations over long distances. Older line-haul locomotives are typically powered by engines of approximately 2000-3000 hp, while newer line-haul locomotives are powered by engines of approximately 3500-5000 hp. In some cases, older line-haul locomotives (especially lower powered ones) are used in switch applications. The industry has been producing higher powered locomotives, with some new models having 4400hp. The development of line-haul locomotives with even higher horsepower ratings, such as 6000 hp or more continues, but it is not clear if this will be the future of locomotive engines.

1.2.2.1.2 Type of Propulsion Systems

Locomotives can be subdivided into three general groups on the basis of the source of energy powering the locomotive: 1) “all-electric” 2) “engine-powered” 3) “hybrid”. In the "all-electric" group, externally generated electrical energy is supplied to the locomotive by means of an overhead contact system, these types of locomotives have existed for over 125 years. An example of this type of locomotive is commonly seen on commuter trains. Power to operate the locomotive is not generated by an onboard engine. Emission control requirements for all-electric locomotives would be achieved at the point of electrical power generation, and thus are not included in this rulemaking.

In the "engine-powered" group of locomotives, fuel (usually diesel in the U.S., although natural gas options are still being pursued) is carried on the locomotive. The energy contained in the fuel is converted to power by burning the fuel in the locomotive engine. A small portion of the engine output power is normally used directly to drive an air compressor to provide brakes for the locomotive and train. However, the vast majority of the output power from the engine is converted to electrical energy in an alternator or generator which is directly connected to the engine. This electrical energy is transmitted to electric motors (traction motors) connected directly to the drive wheels of the locomotive for propulsion, as well as to motors which drive the cooling fans, pumps, etc., necessary for operation of the engine and the locomotive.[D] In the case of passenger locomotives, electrical energy is also supplied to the train’s coaches for heating, air conditioning, lighting, etc. (i.e., "hotel power"). In some passenger trains, electrical energy required for the operation of the passenger coaches is supplied by an auxiliary engine mounted either on the locomotive or under the floor of passenger cars.

The third category "hybrid" is a combination of the "electric" and "engine-powered" groups, and was first developed and used in the 1920’s, although at the time it wasn’t very successful. Today’s technology is considered “battery dominant” and uses a small diesel engine and generator to charge a battery pack; the battery pack will then supply energy on demand to the traction motors.[32] The engine can be 250-640hp (200-480kW) and will typically operate at a constant speed, which is optimized for efficiency and will only run to keep the batteries at a certain charge

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[D] Essentially all "engine powered" locomotives used in the U.S. employ a diesel engine and the electrical drive system described. The term "diesel-electric" has therefore become the most common terminology for these locomotives.

level.[33] This technology is currently only available for switcher locomotives, although it is being developed for use in line-hauls.

1.2.2.1.3 Locomotive Design Features and Operation

1.2.2.1.3.1 Sizing Constraints

Similar to the variation in horsepower, locomotive size determines the work it will perform. Switch locomotives tend to be about 40 to 55 feet long, while line-haul locomotives are typically 60 to 76 feet long. Locomotive length is roughly correlated with engine size, and thus the difference in length has become more significant as locomotive engines have become larger and more powerful. Locomotive length is also related to the number of axles that a locomotive has. In the past, the typical locomotive had four axles (two trucks with two axles each). While there still are a large number of four-axle locomotives in service, all newly manufactured line-haul locomotives have six axles (two trucks with three axles each). There are two primary advantages of having more axles on the locomotive. First, additional axles allow locomotives to be heavier, without increasing the load on each individual axle (and thus the load on the rail). Second, six-axle locomotives typically have greater tractive power at low speeds, which can be critical when climbing steep grades. The use of six-axles on a locomotive does increase its overall length, and continues to lead to the discontinuation of the practice of converting old line-haul locomotives into switch locomotives, since these larger six-axle locomotives are typically too long to be practical in most switch applications.

1.2.2.1.3.2 Operation

One unique feature of locomotives that makes them different than other, currently regulated mobile sources is the way that power is transferred from the engine to the wheels. Most mobile sources utilize mechanical means (i.e., a transmission) to transfer energy from the engine to the wheels (or other point where the power is applied). Because there is a mechanical connection between the road, vehicle engine and the wheels, the relationship between engine rotational speed and vehicle speed is mechanically dictated by the gear ratios in the transmission and final drive (e.g., the differential and rear axle). This results in engine operation which is very transient in nature, with respect to changes in both speed and load. In contrast, locomotive engines are typically connected to an electrical alternator or generator to convert the mechanical energy to electricity. As noted above, this electricity is then used to power traction motors which turn the wheels. The effect of this arrangement is that a locomotive engine can be operated at a desired power output and corresponding engine speed without being constrained by vehicle speed. The range of possible combinations of locomotive speed and engine power vary from a locomotive speed approaching zero with the engine at rated power and speed, to the locomotive at maximum speed and the engine at idle speed producing no propulsion power. This lack of a direct, mechanical connection between the engine and the wheels allows the engine to operate in an essentially steady-state mode, in a number of discrete power settings, or notches, which are described below.

Dynamic braking is another unique feature of locomotives setting them apart from other mobile sources. Dynamic braking is especially important given the traction problems that locomotives must overcome. Locomotives generate an enormous amount of power that can be applied to the wheels when they start to roll, however, the use of steel wheels (which provide less rolling resistance) also make it difficult to start moving a locomotive. The ridges on the sides of the wheels provide traction during cornering to keep the wheels on the rails, and some locomotives are equipped with an oil system that puts oil on the sides of the rails to reduce friction on the sides of the wheels during turns and cornering. On straight sections of rail, some locomotives have a built-in system that will put sand on the rails and in order to increase traction.

In dynamic braking the traction motors act as generators, with the generated power being dissipated as heat through an electric resistance grid, this feature decreases overall braking distance and wear on the wheels. While the engine is not generating motive power (i.e., power to propel the locomotive, also known as tractive power) in the dynamic brake mode, it is generating power to operate resistance grid cooling fans, and is essentially dissipated into the air as heat. As such, the engine is operating in a power mode that is different than the power notches or idle settings discussed above. While most diesel-electric locomotives have a dynamic braking mode, some do not (generally switch locomotives). The potential energy that could be recovered during dynamic braking and utilized by the locomotive is one area researchers are focusing on to increase locomotive efficiency. GE has noted that “the energy dissipated in braking a 207-ton locomotive during the course of one year is enough to power 160 households for that year”[34]. It is, however, very difficult to capture and store this energy, the power generated from dynamic breaking is instantaneous and high enough that it cannot be effectively used by the locomotive at the time it is generated. If the energy could be stored in batteries, or a mechanical device such as a flywheel, tremendous fuel savings could be gained, and therefore development of these types of systems continues.[35]

Hotel power or "Head End Power" (HEP) is power used to operate lighting, heating, ventilation and air conditioning, and all other electrical needs of the crew and passengers alike. This power can be provided by the lead locomotive, or by an additional engine, which is then distributed to the rest of the cars as needed. The design of locomotives for use in passenger train service (without additional engines used to provide HEP) provides for a locomotive to be operated in either of two distinct modes. In one mode, the locomotive engine provides only propulsion power for the train. In this mode, the engine speed changes with changes in power output, resulting in operation similar to freight locomotives. In the second mode, the locomotive engine supplies HEP to the passenger cars, in addition to providing propulsion power for the train. Hotel power provided to the passenger cars can amount to as much as 800 kW (1070 hp). In contrast to operation in the non-hotel power mode, the engine speed remains constant with changes occurring in power output when operating in hotel power mode. Thus, the two modes of operation utilize different speed and load points to generate similar propulsion power. These differences in speed and load points mean that locomotive engines will have different emissions characteristics when operating in hotel power mode than when operating in non-hotel power mode.

1.2.2.1.3.3 Design Characteristics

In 1909 Rudolph Diesel helped construct the first diesel locomotive, and in 1918 the first diesel-electric switch locomotives were put into service. By the 1950's diesel-electric had replaced steam powered locomotives because they required less fuel, maintenance, and man-power.[36] Locomotives use diesel engines because they are much more efficient, reliable, and can generate tremendous power. The diesel engine is the most efficient transportation power plant available today. Thermal efficiency of locomotive diesel engines is 40% or higher, which results from high power density (via high turbocharger boost), high turbocharger efficiencies, direct fuel injection with electronic timing control, high compression ratio, and low thermal and mechanical losses. Many locomotive engines achieve the equivalent of one million miles before overhaul.[35] Durability is critical as a locomotive breakdown on the tracks can bottleneck the entire system; road failures are very costly to the railroads because the importance of timeliness to their customers, and the difficulty in getting replacement locomotives to the location of the failure. The trend toward higher power locomotives is naturally resulting in a trend of fewer locomotives per train, thereby increasing the likelihood that a train would become immobilized by the failure of a single locomotive.

Another unique design feature of locomotives is the design of the engine cooling system and procedures used to control engine coolant temperature. Normal practice in locomotive design has been to mount the radiator on the roof of the locomotive and not to use a thermostat. Control of coolant temperature is achieved by controlling the heat rejection rate at the radiator. The rate of heat rejection at the radiator can be controlled by means such as turning fans on and off or employing a variable speed fan drive, or by controlling the amount of coolant flow to the radiator (using non-thermostat controls). A related point of difference between road vehicle and locomotive engine cooling systems is that antifreeze is not generally used in locomotives. Locomotives use water, not antifreeze to cool their engines because water is much more efficient at removing heat. Using antifreeze would require a cooling system approximately 20% larger than the current design (which holds approximately 450 gallons of water).[37] The size of a locomotive is limited by the existing track and tunnel infrastructure which restricts the height, width and length of a locomotive. Locomotives usually run in consists (groups) which means that the one following the lead locomotive will not have the same effective cooling as the one in front since the air it encounters will be warmer. The practice of following creates additional cooling problems especially in tunnels which call for special design considerations.

The final unique design feature noted here is the manner in which new designs and design changes are developed. The initial design of any new models/modifications and production of prototype models are done in much the same manner as is the case with other mobile sources. Locomotive manufacturers indicated that this process can be expected to require from 12 to 24 months for significant changes such as those required to comply with the new Tier 0 standards. Prototype locomotives are typically sold or leased to the railroads for extended field reliability testing, normally of one to two years duration. Only after this testing is completed can the new design/design change be certified and placed into normal production.

1.2.2.2 Line-Haul Manufacturing

1.2.2.2.1 Manufacturers

Locomotives used in the United States are primarily produced by two manufacturers: Electromotive Diesel (EMD) and General Electric Transportations Systems (GETS). EMD manufactures its locomotives primarily in London, Ontario and their engines in La Grange, Illinois. The GETS locomotive manufacturing facilities are located in Erie, Pennsylvania, while their engine manufacturing facilities are located in Grove City, Pennsylvania. These manufacturers produce both the locomotive chassis and propulsion engines; they also remanufacture engines. MotivePower Industries has produced some mid-horsepower locomotives suited for commuter or long-distance service using engines manufactured by Caterpillar, Inc,. MotivePower's Wabtec division also manufactures a switcher locomotive that runs on liquefied natural gas. The Cummins Engine Company, Inc. produces V12 and V16 diesel engines for use in locomotives. The EPA has identified four locomotive diesel manufacturers, one of which can be considered a small business according to SBA guidelines. There are also a few companies such as Steward and Stevenson or Brookville Mining Equipment that manufacture small switch locomotives (under 700 bhp) for use in mines or for companies who need to move a few cars around a local yard.

EMD was founded in 1922 and acquired by General Motors in 1930; EMD was sold in 2005 by General Motors to the Greenbriar Equity Group and Berkshire Partners, and is now called Electro-Motive Diesel, Inc. While they primarily manufacture a 2-stroke diesel locomotive engine, they started manufacturing a 4-stroke engine in 1997. They currently produce five national models ranging from 3000-6000hp, and have other international models as well as custom built locomotives.[38] EMD employs approximately 2,600 people and designs, manufactures, market, sells and services freight and passenger diesel-electric locomotives worldwide. GE was formed by Thomas Edison who developed his first experimental electrical locomotive in 1880, they also built and put into the service the world’s first diesel-electric switcher locomotive in 1924 that remained in service until 1957. GE currently produces at least five national models, two international models, passenger locomotives and is developing a hybrid locomotive.[39] GE’s Transportation division employs approximately 8,000 people and also engineers, manufactures, markets and services their diesel locomotive products worldwide.

1.2.2.2.2 Production

Due to the long total life span of locomotives and their engines, annual replacement rates of existing locomotives with freshly-manufactured units are very low. EPA estimated a replacement rate for locomotives and locomotive engines based on historical data supplied by AAR, Table illustrates the historical replacement rates for locomotives in the Class I railroad industry. Sales of new locomotives have averaged approximately 780 units per year over the last ten years. This replacement rate indicates a fleet turnover time of about 30 years for Class I railroads. Fleet turnover is the time required for the locomotive fleet to be entirely composed of locomotives that were not in service as of the base year. Class II an III railroads generally buy used locomotives from Class I railroads, although some are purchasing new switchers and a few line-hauls.

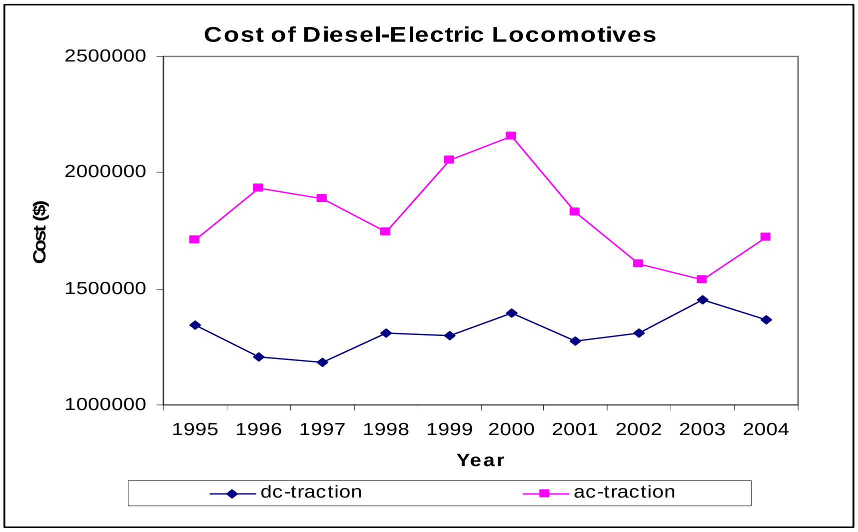
Table 1-28 Class I New Locomotive Turnover Rates[40]

Year	Number of New Locomotives Installed	Number of Remanufactured Locomotives Installed	Total Number of Locomotives in Service	Percent Turnover of New
1995	928	201	18,812	4.9%
1996	761	60	19,269	3.9%
1997	743	68	19,684	3.8%
1998	889	172	20,261	4.4%
1999	709	156	20,256	3.5%
2000	640	81	20,028	3.2%
2001	710	45	19,745	3.6%
2002	745	33	20,506	3.6%
2003	587	34	20,774	2.8%
2004	1,121	5	22,015	5.1%

1.2.2.2.3 Cost

The cost of AC-traction locomotives can be as high as $2.2 million, while DC locomotives are usually less than 1.5$ million. Figure 1-7 shows data from the AAR's Railroad Ten-Year Trends 1995-2004 publication. Some of the variation from year to year can be attributed to differences in features, but it appears the overall trend is the price of AC locomotives seems to be coming down, while DC locomotives remain about the same.

Figure 1-7 Cost of New Locomotives[1]



1.2.2.3 Switcher Manufacturing

1.2.2.3.1 Manufacturers

The majority of switchers in operation today are former line-haul locomotives that have been assigned to a yard, and they are usually quite old. This trend will most likely wane over time because of the size and power of most new locomotives, which make them unsuitable for switching operations. While EMD does offer a traditional new switch locomotive, other companies are offering switchers with alternative power plants that are usually built off of an old switcher platform.

Motive Power, headquartered in Wilmerding, PA offers a switching locomotive fueled by liquefied natural gas, which they will build on a core supplied by a railroad. Motive Power is a large company with nearly 5,000 employees; they service other industries such as marine, transit and power generation. National Railway Equipment Co. (NREC) based in Houma, Louisiana with facilities also in Illinois manufactures a “gen-set” switcher locomotive (powered by multiple smaller diesel engines) that is completely built by them from the ground up. They employ approximately 150 employees. RailPower Technologies, is headquartered in Brossard, Quebec but also has an American office in Erie, Pennsylvania; they employ approximately 100 people. RailPower manufactures the Green Goat® hybrid yard switcher and is developing a natural gas switcher locomotive as well, and they also use an old switcher locomotive core to build their platform on.

1.2.2.3.2 Production

Multi gen-set switchers are a falling back into favor; they were originally used in the late 1920's in some applications. The existing fleet of retired line-haul switcher locomotives turns over very slowly, and production of alternative technology switchers is beginning to increase. NREC is working with UP and is building sixty

2,100hp triple-engin GS21B gensets equipped with four-cycle, six-cylinder 700hp Cummins QSK-19 engines, these switchers are purported to reduce NO_x and PM by 80% as compared to reduce fuel consumption by up to 40%. Railpower has also been asked by UP to build 80 triple-engine switchers on the GreenGoat platform and they have noted that their system can reduce fuel consumption by up to 35% and NO_x and PM emissions by 80%, Norfolk Southern has ordered two of these from RailPower in the form of rebuild kits where their own maintenance staff will install this triple-engine system during a switcher rebuild.[41] New switchers can cost upwards of $1.5 million dollars, the GreenGoat hybrid switcher can cost as little as $700,000 if a customer supplies a completely reconditioned GP-9 locomotive.[42] The price of these and other switchers depends on whether or not a core is supplied and what features it will be built with.

1.2.2.3.3 Trends

Trends: remote control locomotives have been used in Canada and the U.S. for many years; however, Class I railroads have recently begun to implement this on a wider scale according to the FRA. Although this is mainly a switch yard function, this type of operation may be applied on line-hauls as well in the future. This may affect cab design and what necessary equipment is built into future switchers, for example if it is a remote control unit it wouldn’t need cab comfort equipment such as heaters or air conditioners. Many new switchers have been retrofitted with idle reduction devices to decrease fuel consumption and increase the railroads efficiency.

1.2.2.4 Remanufactured Locomotives

Since most locomotive engines are designed to be remanufactured a number of times, they generally have extremely durable engine blocks and internal parts. Parts or systems that experience inherently high wear rates (irrespective of design and materials used) are designed to be easily replaced so as to limit the time that the unit is out of service for repair or remanufacture. The prime example of parts that are designed to be readily replaceable on locomotive engines are the power assemblies(i.e., the pistons, piston rings, cylinder liners, fuel injectors and controls, fuel injection pump(s) and controls, and valves). Within the power assemblies, parts such as the cylinder head in general do not experience high wear rates, and may be reused after being inspected and requalified (determined to be within manufacturers specifications). The power assemblies can be remanufactured to bring them back to as-new condition or they can be upgraded to incorporate the latest design configuration for that engine. In addition to the power assemblies there are numerous other parts or systems that may also be replaced.[E] Engine remanufactures may be performed either by the railroad that owns the locomotive or by the original

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[E] Bottom end components, such as crankshafts and bearings, are often remanufactured only during every other remanufacture event. Remanufacture events that do not include these bottom end components are sometimes referred to as "partial remanufactures" manufacturer of the locomotive. Remanufactures are also performed by companies that specialize in performing this work.

During its forty-plus year total life span, a locomotive engine could be remanufactured as many as ten times (although this would not be considered the norm). Locomotive engine remanufacturing events are thus routine, and are usually part of the scheduled maintenance. It is standard practice for the Class I railroads within the railroad industry to remanufacture a line-haul locomotive engine every four to eight years. Typically newer locomotives, which have very high usage rates, are remanufactured every four years. Older locomotives usually are remanufactured less frequently because they are used less within each year. Such remanufacturing is necessary to insure the continued proper functioning of the engine. Remanufacturing is performed to correct losses in power or fuel economy, and to prevent catastrophic failures, which may cause a railroad line to be blocked by an immobile train.

When a locomotive engine is remanufactured, it receives replacement parts which are either freshly-manufactured or remanufactured to as-new condition (in terms of their operation and durability).[F] This includes the emission-related parts which, if not part of the basic engine design, are also generally designed to be periodically replaced. The replacement parts are also often updated designs, which are designed to either restore or improve the original performance of the engine in terms of durability, fuel economy and emissions. Because of a locomotive engine's long life, a significant overall improvement in the original design of the parts, and therefore of the engine, is possible over the total life of the unit. Since these improvements in design usually occur in the power assemblies (i.e., the components where fuel is burned and where emissions originate), remanufacturing of the engine essentially also makes the locomotive or locomotive engine a new system in terms of emission performance. A remanufactured locomotive would therefore be like-new in terms of emissions generation and control.

While Class I locomotives are remanufactured on a relatively frequent and scheduled basis of 4 to 8 years, Class II and III locomotives may be remanufactured on a longer schedule or may not be remanufactured at all. The typical service life of a locomotive (40 years) is often exceeded by small railroads that continue to use older locomotives. It is important to note that there is no inherent limit on how many times a locomotive can be remanufactured, or how long it can last. Rather, the service life of a locomotive or locomotive engine is limited by economics. For example, in cases, where it is economical to cut out damaged sections of a frame, and weld in new metal, an old locomotive may be salvaged instead of being scrapped. Remanufacturers can also replace other major components such as the trucks or traction motors, to allow an older locomotive to stay in service. However, at some point, most railroads decide that the improved efficiency of newer technologies

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[F] In some cases, some components are remanufactured by welding in new metal and remachining the component to the original specifications.

justifies the additional cost, and thus scrap the entire locomotive. Nevertheless, many smaller railroads, especially switching and terminal railroads, are still using locomotives that were originally manufactured in the 1940s.

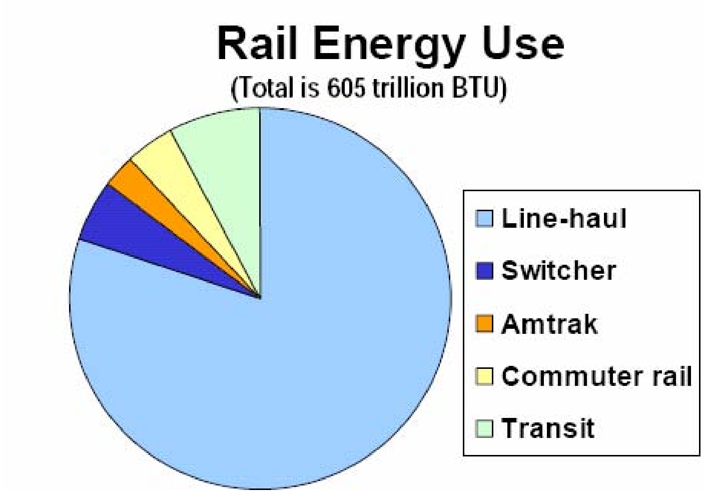
1.2.2.4.1 Remanufacturers

While the original manufacturers provide much of the remanufacturing services to their customers, there are several smaller entities that also provide remanufacturing services for locomotive engines. These businesses can be rebuilders licensed by the OEMs, in addition to the OEMs themselves. Moreover, some of the Class I and II railroads remanufacture locomotive engines for their own units and on a contract basis for other railroads. EPA has been able to identify nine independent locomotive remanufacturers, four of which are small business entities. Many of these businesses are full service operations that remanufacture locomotive assemblies (such as trucks or air brake systems), sell new and used parts, repair wrecked locomotives or provide routine maintenance. A few apparently remanufacture locomotives primarily for resale or lease, while others remanufacture engines for operating railroads or industrial customers. A few also offer contract maintenance; this may be tied to a locomotive lease, or may be offered separately to owners of locomotives. The size of these companies vary tremendously as some have as few as two employees, while others can have up to 5,000 employees. The cost of remanufacturing kits can vary depending on the model of locomotive and year of manufacture, an estimated range is \$15,000 - \$30,000 per kit.

1.2.3 Demand: Railroads

Railroads transport freight more efficiently than other modes of surface transportation because they require less energy and emit fewer pollutants.[43] The 2006 Transportation Energy Data Book shows that rail transportation used approximately 7.4% of all diesel fuel used in transportation and 2.1% of the total energy used by all forms of transportation to move 22.1% of all freight ton-miles (miles one ton of freight is moved). It also shows that this is less than 1% of the total U.S. energy use, but that locomotives currently emit slightly less than one million tons of NO_x each year, which is about 4% of total NO_x emitted by all sources. It is important to recognize, however, that the 2.1% of energy used by rail transportation (625.5 trillion BTUs) is the total of all rail sectors including: line-haul, switcher, Amtrak, commuter rail, and transit rail, as shown in Figure 1-9. This means that the freight railroads use approximately 1.86% of all energy consumed by every source of transportation to haul 22.1% of all ton-miles.

Figure 1-8 Rail Energy Use



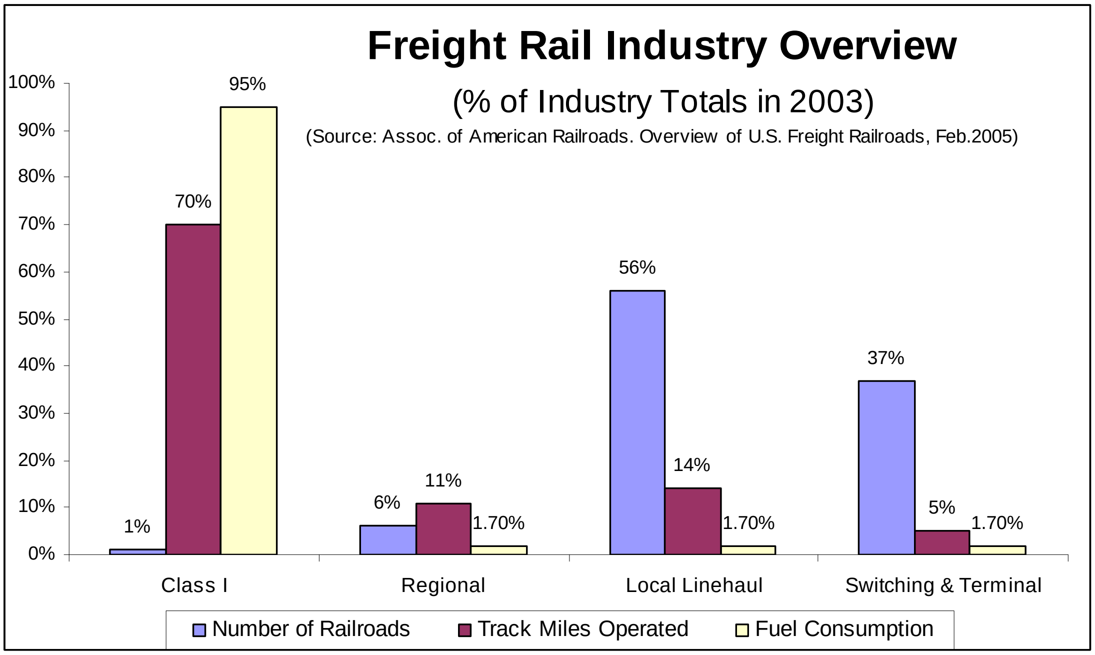
Source: Linda Gains, "Reduction of Impacts from Locomotive Idling", Argonne National Laboratory, 2003

There are many other unique characteristics of the railroad industry such as track sharing, locomotive sharing, and fleet age. Unlike most other methods of shipping, railroads are responsible to maintain their own infrastructure such as tracks, and bridges, which is a very expansive network. The Class I railroads spent more than $320 billion or approximately 44% of their operating revenue between 1980-2003 to maintain and improve their infrastructure and equipment.[44] As locomotives grow larger and heavier, and as cars are designed to hold more weight, track is required that can handle this increased load, and this is quite costly. To date, of the 549 short line and regional railroads in existence, 333 have track that cannot handle these increased loads.[45]

1.2.3.1 Railroad Classification System (Class I, II and III)

In the United States, freight railroads are subdivided into three classes based on annual revenue by the Federal government's Surface Transportation Board (STB) (STB regulations for the classification of railroads are contained in 49 CFR Chapter X). The STB regulations divide the railroads into three classes based on their annual carrier operating revenue[46]. As of 2004, Class I railroads are those with annual carrier operating revenues of at least $289.4 million, Class II railroads are those with annual carrier operating revenues between $23.1-$289.3 million, Class III railroads are those with annual carrier operating revenues of $23.1 or less. The AAR further subdivides Class II and III railroads based on the miles of track over which they operate and their revenue. These categories are then called Short Line and Regional Railroads and usually belong to the American Short Line and Regional Railroad Association (ASLRRA).

Figure 1-9 Freight Rail Industry Overview



1.2.3.2 Class I Characteristics

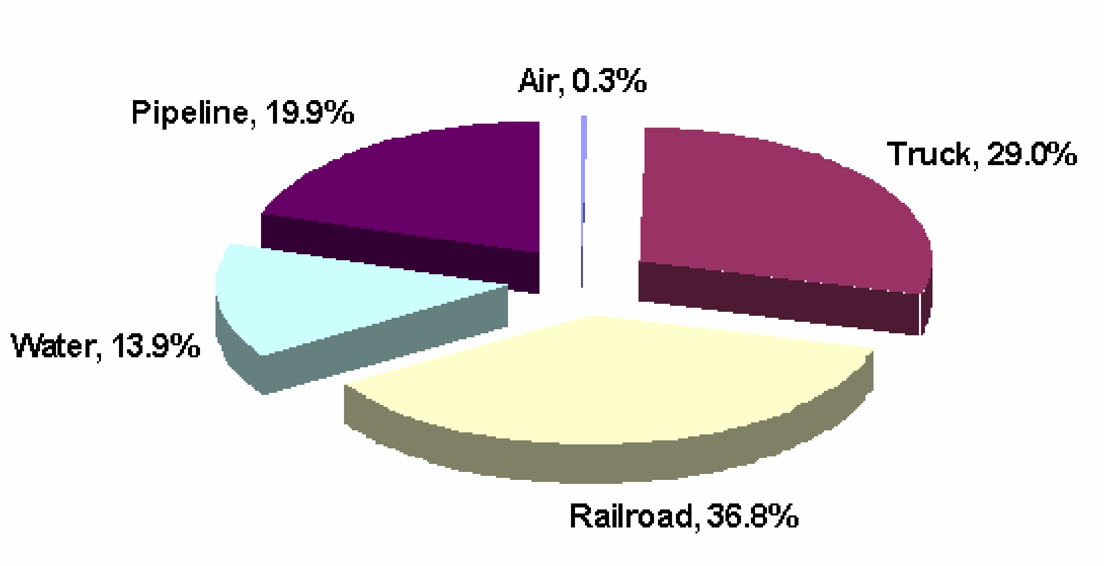
Current railroad networks (rail lines) are geographically widespread across the United States, serving every major city in the country. Approximately one-sixth of the freight hauled in the United States is hauled by train.[48] There are few industries or citizens in the country who are not ultimate consumers of services provided by American railroad companies. According to statistics compiled by AAR, Class I rail revenue accounted for 0.36 percent of Gross National Product in 2004. Thus, efficient train transportation is a vital factor in the strength of the U.S. economy.

In order for Class I railroads to operate nationally, they need unhindered rail access across all state boundaries. If different states regulated locomotives differently, a railroad could conceivably be forced to change locomotives at state boundaries, and/or have state-specific locomotive fleets. Currently, facilities for such changes do not exist, and even if switching areas were available at state boundaries, it would be a costly and time consuming disruption of interstate commerce. A disruption in the efficient interstate movement of trains throughout the U.S. could have an impact on the health and well-being of not only the rail industry, but the entire U.S. economy as well.

The Class I railroads are the nationwide, long-distance, line-haul railroads which carry the bulk of the railroad commerce. There are currently 7 Class I freight railroads operating in the country, two of which are Canadian owned. Class I railroads operated approximately 22,400 locomotives in the U.S., over 97,662[G] miles of track and accounted for approximately 90 percent of the ton-miles of freight hauled by rail annually and consumed 4.1 billion gallons of diesel fuel in 2004.[47,48] Of these, the two largest Class I railroads, BNSF, and Union Pacific, accounted for the vast majority (63%) of the Class I locomotives in service in the U.S as of the end of 2004.[49] According to the 2004 AAR's' Analysis of Class I Railroads, Class I railroads paid on average $1.06 for a gallon of fuel in 2004 for a total expenditure of $4.2 billion which was 11% of their operating revenue. U.S. Class I railroads employ approximately 177,000 people, the vast majority of whom are unionized, and as of 2004 receive an average compensation of $65,500.[49]

The Bureau of Transportation Statistics 2006 report shows that in terms of ton-miles of freight, railroads haul 36.8% of total ton-miles, followed by trucking (29%), pipline (19.9%), river/canal/barge (13.9%), and air (0.3%), also shown in Figure 1-10 . Rail is a primary means of transport for many bulk commodities, according to AAR, 65% of all coal produced in the U.S., 33% of all grain harvested in the U.S. and 75% of all new automobiles manufactured in the U.S. were transported by rail. Being a primary source/mode of transporting these items, the railroad industry normally sets the industry standard price ($/ton-mile). Rail transport is typically more fuel efficient and less expensive than other land-based sources of transport. In terms of BTUs of energy expended per ton-mile of freight hauled, Department of Energy statistics indicate that rail transport can be as much as three to four times more efficient than truck transport. The AAR has asserted that one double-stack train can carry the equivalent of 280 truckloads of freight.[50]

Figure 1-10 U.S. Freight Transportation Share by Mode



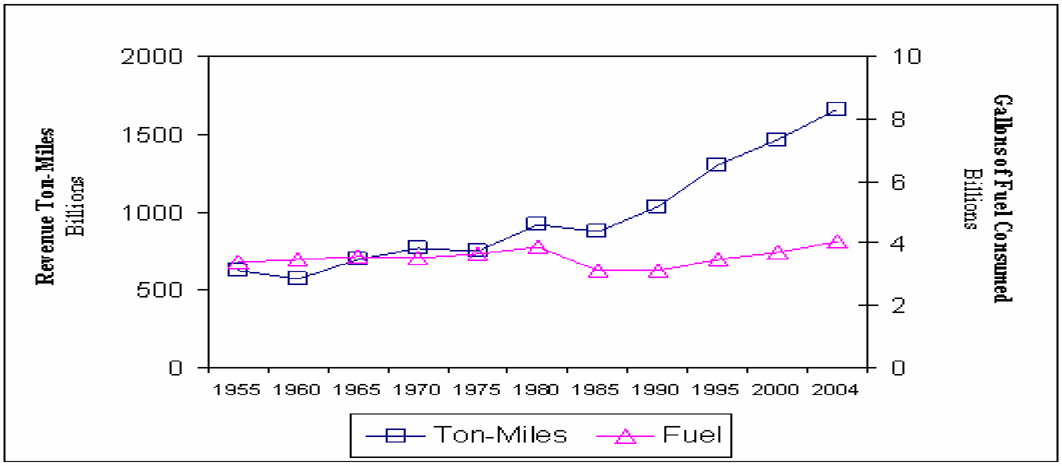
[G] This is the road length of track or the aggregate length of track excluding sidings and parallel tracks, actual track miles are 167,312.

Figure 1-12 and Table 1-29 show the long term growth trends for the amount of freight carried by Class I railroads and the amount of fuel consumed in carrying that freight.[51] As can be seen from these data, the ton miles of freight carried have almost tripled, while total fuel consumption has risen only 10-20%, showing an approximate 250% improvement in freight hauling efficiency.[i] The reason for this is that locomotive manufacturers have made continual progress in improving the fuel efficiency of their engines and the electrical efficiency of their alternators and motors, and railroads have made significant improvements to their operational efficiency. Fuel efficiency of the railroad industry overall has improved 16% over the last decade.[43] It is reasonable to project that the growth in the amount of freight hauled will continue in the future. It is less certain, however, whether fuel consumption will increase significantly in the near future.

Table 1-29 Annual Fuel Consumption and Revenue Freight For Class I Railroads

Annual Fuel Consumption and Revenue Freight For Class I Railroads			
Year	Revenue Freight (Million Ton-Miles)	Fuel Consumption (Million Gallons)	Ton-Miles of Freight moved per gallon of fuel
1960	572,309	3,463	165
1970	764,809	3,545	216
1980	918,958	3,904	235
1990	1,033,969	3,115	332
1995	1,305,969	3,480	375
2000	1,456,960	3,700	394
2001	1,495,472	3,710	403
2002	1,507,011	3,730	404
2003	1,551,438	3,826	405
2004	1,662,598	4,059	410

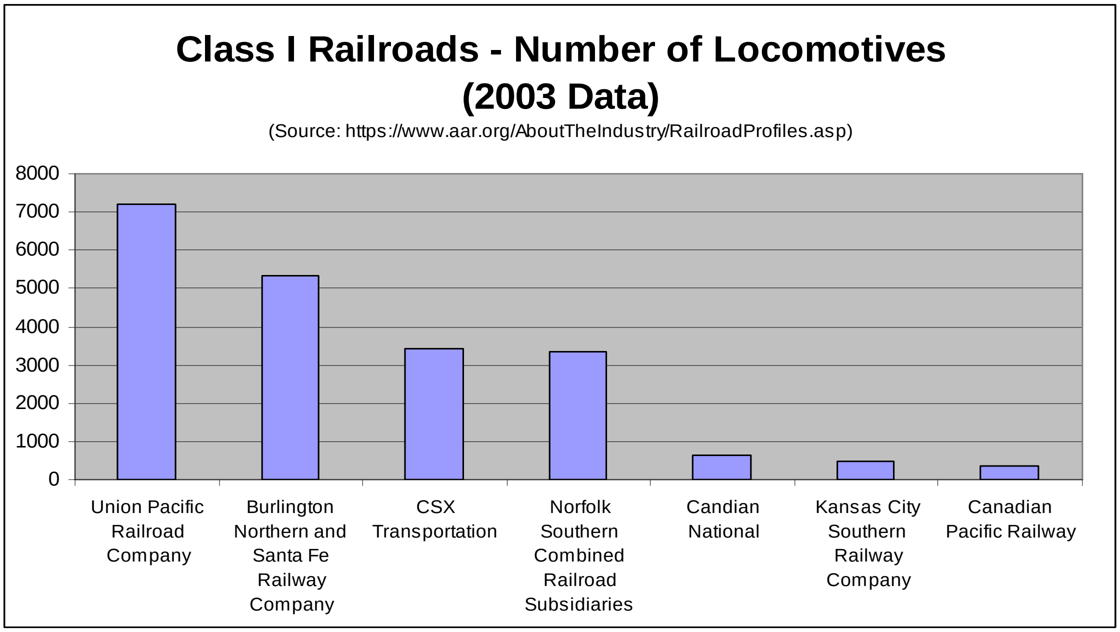
Figure 1-11 Fuel Consumption and Revenue Ton-Miles for Class I Railroads



1.2.3.2.1 Class I Market Share

Union Pacific (UP) operates over the most miles of track (32,616), has the largest number of employees (49,511), the greatest operating revenue ($12,180 million), but is surpassed in revenue ton-miles[H] by BNSF (569 billion). UP owns more miles of track than any other Class I (27,123), and operates the most locomotives (7,680), as show in Table I-30.

Table 1-30 Class I Railroads - Number of Locomotives



1.2.3.2.2 Locomotive Fleet

Purchasing practices have historically been for Class I railroads to buy virtually all of the freshly-manufactured locomotives sold. As the Class I railroads replace their equipment with freshly-manufactured units, the older units are either sold by the Class I railroads to smaller railroads, are scrapped, or are purchased for remanufacture and ultimate resale (or leasing) by companies specializing in this work. The industry-wide replacement rate for locomotives would therefore actually be lower than those indicated for the Class I railroads only. This would mean that the time required for the total locomotive fleet to turn over would be longer.

Additionally, independent of cyclic changes in the industry, future locomotive replacement rates could actually decrease. Locomotive manufacturers are now producing locomotives that have significantly more horsepower than older

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[H] A revenue ton-mile is calculated by dividing freight revenue by total freight ton-miles, it is a measure of the level of revenue received by a railroad for hauling weight over distance. (AAR Railroad Facts, 2006) locomotives. Railroads have requested this change so that fewer locomotives are needed to pull a train. Placing more horsepower on a locomotive chassis increases overall train fuel efficiency. For example, it would be more fuel-efficient to use two 6000 hp locomotives, rather than three 4000 hp locomotives, to pull the same weight train, because the weight of an entire locomotive can be eliminated. Thus, whereas three old locomotives may be scrapped, only two new locomotives may need to be bought as replacements.

On the other hand, the business outlook for the railroad industry has been improving in the last few years. As railroads have become increasingly cost-competitive, they are attracting more business. This in turn increases demand for locomotive power to move the additional freight. Thus, while purchases of new locomotives may increase in the next few years, these locomotives will likely supplement, rather than replace, existing locomotives. Moreover, if freight demands continue to increase, it may become cost-effective to operate locomotives for longer periods than are estimated here.

1.2.3.2.3 Operation Profile

1.2.3.2.3.1 Fuel consumption.[52]

Class I railroads consumed 531 trillion BTUs in 2003. Locomotives traveled 1,538 million unit-miles in 2004, and averaged 69,900 miles per locomotive in 2004. The Surface Transportation Board reported that Class I railroads consumed 4.1 billion gallons of diesel fuel in 2004, for an average mile traveled per gallon of 0.13. Amtrak traveled 37 million train miles in 2004, and consumed 69.9 million gallons of fuel. The 4.1 billion gallons of diesel fuel used by the Class I railroad's is 96% of all locomotive fuel used in the U.S. and 7.4% of all diesel fuel used for transportation in the United States. Class I railroads spent $4.2 billion which is 11% of total operating expenses on fuel in 2004. The railroads are continually trying to reduce their fuel consumption through efforts such as idle reduction, and other operational improvements. In a study done by the Department of Energy, the aerodynamic drag of coal cars has been shown to account for 15% of total round-trip fuel consumption for a coal train, intermodal cars that are double stacked also carry an aerodynamic fuel consumption penalty of about 30% loss due to drag. Experiments have developed some fairings and foil that can reduce this drag loss on coal cars by up to 5% which would save 75 million gallons or 2% of total Class I fuel consumption in 2002.

1.2.3.2.3.2 Maintenance Practices

Locomotive maintenance practices also present some unique features. As is the case with other mobile sources, locomotive maintenance activities can be broken down into a number of subcategories. Routine servicing consists of providing the fuel, oil, water, sand (which is applied to the rails for added traction), and other expendables necessary for day-to-day operation. Scheduled maintenance can be classified as light (e.g., inspection and cleaning of fuel injectors) or heavy, which can range from repair or replacement of major engine components (such as power assemblies) to a complete engine remanufacture. Wherever possible, scheduled maintenance, particularly the lighter maintenance, is timed to coincide with periodic federally-required safety inspections, which normally occur at 92-day intervals. Breakdown maintenance, which may be required to be done in the field, consists of the actions necessary to get a locomotive back into service. Because of the high cost of a breakdown in terms of lost revenue that could result from a stalled train or blocked track, every effort is made to minimize the need for this type of maintenance. In general, railroads strive to maintain a high degree of reliability, which results in more rigorous maintenance practices than would be expected for most other mobile sources. However, the competitive nature of the business also results in close scrutiny of costs to achieve the most cost-effective approach to achieving the necessary reliability. This has resulted in a variety of approaches to providing maintenance.

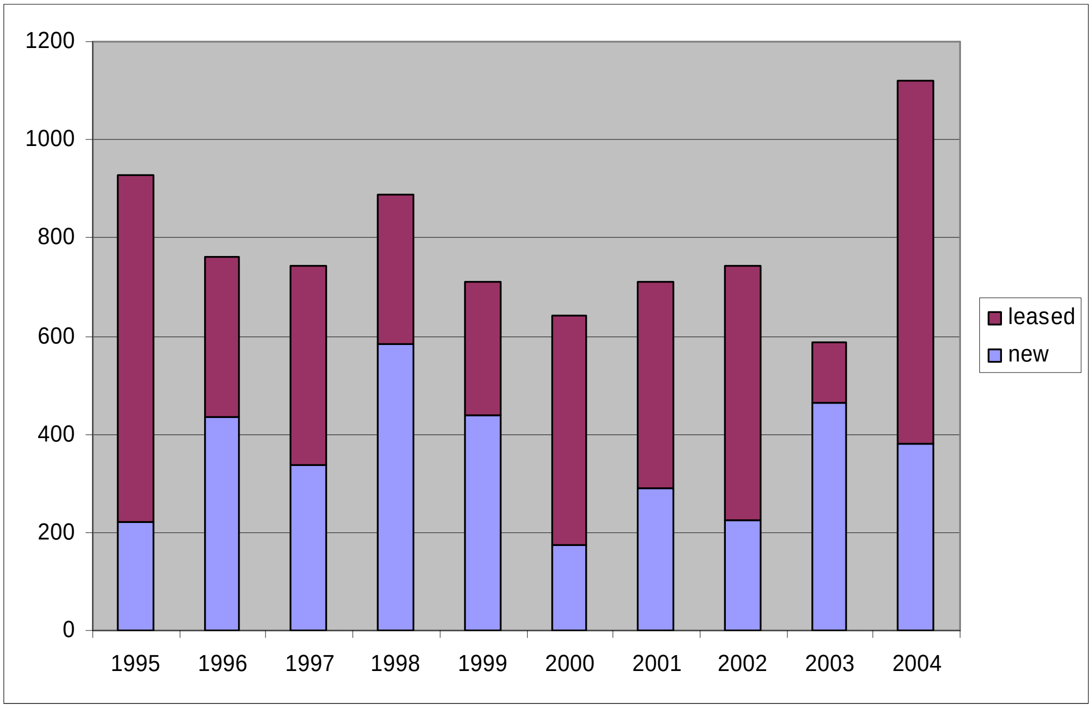
Maintenance functions were initially the purview of the individual railroads. Some major railroads with extensive facilities have turned to providing this service for other railroads, and a few of the smaller railroads also have done the same, in particular for other small railroads. However, the tendency in recent years has been toward a diversification of maintenance providers; a number of independent companies have come into existence to provide many of the necessary, often specialized services involved (e.g., turbocharger repair or remanufacture). The trend toward outside maintenance has also been accelerated by the policies of some of the larger railroads to divest themselves of not only maintenance activities, but ownership of locomotives as well. The logical culmination of this trend is the "power by the mile" concept, whereby a railroad can lease a locomotive with all the necessary attendant services for an agreed-upon rate.

1.2.3.2.4 Leasing

Locomotives are available for lease from OEMs, remanufacturers, and a small number of specialized leasing companies formed for that purpose. Leasing practices appear to be fairly standardized throughout the industry. Although lease contracts can be tailored on an individual basis, most leases seem to incorporate standard boilerplate language, terms and conditions. Under a typical lease, the lessee takes on the responsibility for safety certification and maintenance (parts and scheduled service) of the locomotive (including the engine), although these could be made a part of the lease package if desired. The lease duration ranged between 30 days and 5 years, with the average being 3 years

As can be seen from Figure 1-12 leasing has been a continuing trend among Class I railroads, with almost two-thirds of the locomotives placed in service in 2004 being leased. Leasing among Class II and III railroads is not nearly as widespread.

Figure 1-12 Source: AAR Railroad Ten-year Trends 1995-2004 : Number of Purchased and Leased Class I Locomotives



1.2.3.2.5 Traffic[52]

Between 1993-2002 the value of goods being transported by all modes of transportation increased by 43.6% to $8,397.2 billion, and the ton miles increased over that period by 29.6% to 3,137.9 billion ton-miles. The railroads share of the value market increased during that time by 25.7%, and the percent increase in their ton-miles shipped over that time was 33.8%. Ton-miles shipped using multiple modes of transportation also increased over this period such as Truck and Rail (20.8%) and rail and water (63.8%).

Figure 1-13 shows that the overall Class I traffic volumes are still increasing, and as the car miles and train miles converge, this means they are optimizing the number of cars a locomotive can carry most likely by using fewer more powerful locomotives to haul more cars.[48] The average length of a haul for Class I railroads has generally increased every year, and has almost doubled since 1960 when 461 miles was the average haul as compared to 2004 where 862 miles is the average haul length, commuter rail has not really increased its average haul length over this same time period. Class I train-miles, (a train-mile is the movement of a train, which can consist of multiple cars, the distance of one mile) were 535 million in 2004, Class I car-miles (a car-mile measures the distance traveled by every car in a train) were 37,071 million miles in 2004.

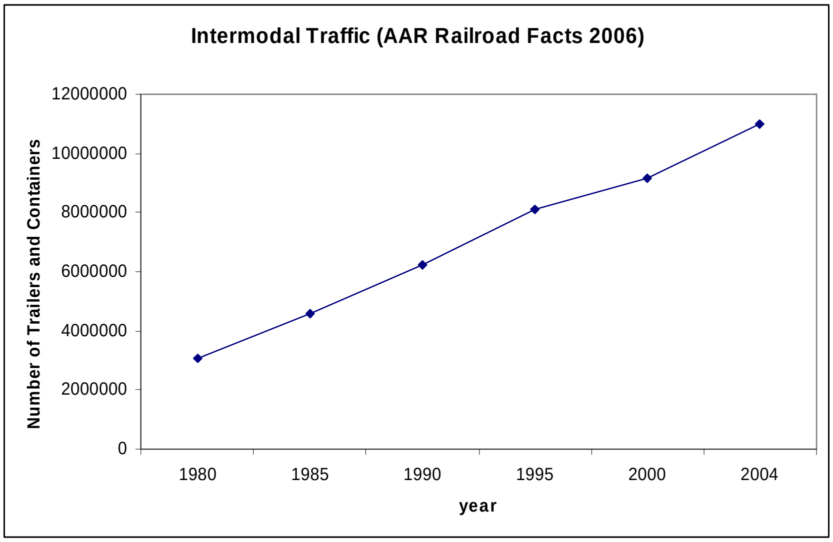
Figure 1-13 Class I Train Miles and Car Miles Source: AAR Ten Year Trends 1995-2004

1.2.3.3 Hauling Statistics[52]

Class I railroads hauled 1,603,564 million ton-miles of freight in 2003, which was 37% of all freight hauled in the US; they also carried 19.8 billion ton-miles of crude oil and petroleum products, which was 2.2% of all those products, trucks carried 3.8%, but the bulk is transported via pipeline (66.8%) or water carriers (27.2%). As of 2002, railroads transported 72.1 billion ton miles of hazardous materials, or 22.1% of all hazardous material being shipped an average of 695 miles per shipment (BTS 2006). Railroads and trucks carry roughly equal hazmat ton-mileage, but trucks have nearly 16 times more hazmat releases than railroads.[56]

The 2006 FRA Freight Railroad Overview indicates that intermodal shipping is the fastest growing segment of rail traffic, doublestack containers were introduced in the 1980's and since then number of trailer and container loadings has risen from 3.4 million to 11.0 million in 2004. Figure 1-14 shows the near doubling of this traffic in each of the past two decades. The Staggers Act of 1980 also legalized railroad-shipper contracts, and according the STB, at least 55% of all traffic moves under contract, which allows railroads to increase efficiency by permitting better planning.

Figure 1-14 Class I Intermodal Traffic Source: AAR Railroad Facts 2006 Edition



1.2.3.4 Track Statistics

As of 2004, Class I owned 97,662 miles of road Since 1980, capital expenditures on roadway and structures has increased 88% from 2.6 billion in 1990 to 4.9 in 2004 as railroad tracks have been upgraded to 130 pound per yard weighted rail to accommodate heavier loads being hauled per car. Class I railroads have increased their traffic (ton-miles) by approximately 81%, while they have decreased the miles of track they own by 41%. This has increased traffic density, and although double-stacking containers has helped to reduce traffic to some degree, this is still a concern due to the continual growth in ton-miles.

1.2.3.5 Class II & III Characteristics[53]

In the 1970's, deregulation allowed the Class I railroads to stop serving many smaller lines that were unprofitable to them. This allowed many small independent railroads to take over that portion of the line and run it more efficiently and sometimes at a lower cost due to their enhanced flexibility as a small business, in 2004 there were 549 Class II and III railroads. In many cases, these smaller railroads are also able to receive financial assistance from local governments or associations of customers to help them upgrade their infrastructure (in many cases, the tracks are quite old and are not rated for the loads that today's cars typically carry).

In 2004, Short Lines originated or terminated one out of every four carloads moved by the domestic rail industry, and operated over approximately 50,000 miles of track, which is nearly 29% of all U.S. rail mileage. They had over 19,000 employees and served over 11,700 customers and facilities. Of the track they operate, only 43% is capable of handling the heavier 286,000 axle weight cars. The total revenue for the Class II and III railroads in 2004 was almost $3 billion, while they spent nearly $433 million on capital expenditures, $397 million on maintenance of equipment, road and structures, and $221 million on fuel. More than half of the short line and regional railroads connect to two or more other railroads, and over 80% operate in one state only.

Statistics compiled by the American Short Line and Regional Railroad Association (ASLRRA) 2004 show that there are approximately 549 Class II and III railroads (not including commuter and insular railroads). A more detailed breakdown of these can be found in Table 1-31. They consist primarily of regional and local line-haul and switching railroads[I], which operate in a much more confined environment than do the Class I railroads. Class II and III railroads operate approximately 3,777 locomotives. In a recent survey taken by the ASLRRA, locomotive fleet age data shows that over 92% of the locomotives owned by the Class II and III railroads are over twenty years old, 5.4% are 10-19 years old, and 2% are newer than 10 years old. Class II and III railroads used 552 million gallons of fuel in 2004, which is about 13% of the amount of diesel fuel used by Class I locomotives in 2004. Employment has declined for all railroads substantially since the 1990's, but all railroads are predicting growth in hiring.

Table 1-31 Profile of Railroad Industry -2004[54]

Type of Railroad	Number of Railroads	Number of Employees
Class I Freight Railroad	7	157699
National Passenger Railroads	1	18,909
Regional Railroads	31	7422
Local/Line-Haul Railroads	314	5349
Switching and Terminal	204	6429
Class I Subsidiaries	102	3687
Commuter Railroads	18	25,29655
Shipper-Owned Railroads	***68***	
Government Owned Railroads	***28***	

Some of the smaller railroads are owned and operated by Class I railroads, many of which are operated as formal subsidiaries for financial purposes, but are run as standalone entities. In 2004, there were 31 regional railroads, 314 local line-haul railroads and 204 switching and terminal railroads, including subsidiaries (regional and local railroads may also have subsidiaries). A few of these are publicly held railroads and some are shipper-owned. Insular in-plant railroads are not included in this total. ASLRRA estimated that there are probably about 1,000 insular railroads in the U.S**.** These railroads are not common carriers, but rather are dedicated to in-plant use. They typically operate a single switch locomotive powered by an engine with less than 1000 hp. Such locomotives typically use a few thousand gallons of diesel

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[I] "Regional railroad" and "local railroad" are terms used by AAR that are similar, but not identical, to "Class II" and "Class III", respectively.

fuel each year, and thus are not a particularly significant source of emissions. Finally, there are a handful of very small passenger railroads that are primarily operated for tours. These tourist railroads are included within the Class II and III railroads.

1.2.3.6 Passenger Rail

1.2.3.6.1 Amtrak

Amtrak was formed in 1971 by Congress through the Rail Passenger Service Act of 1970 (P.L. 91-518, 84 Stat.1327) to relieve the railroads of the financial burden of providing passenger railway service. In return for government permission to leave the passenger rail business and avoid massive losses, many of the freight railroads donated equipment to Amtrak as well as $200 million in startup capital.[56] Amtrak is operated by the National Railroad Passenger Corporation of Washington, D.C. The Secretary of Transportation has the authority to designate Amtrak's destinations, which as of 2004 included 527 cities; other transit rail serves 2,909, some of which may be shared with Amtrak (STB 2006). [52] On average, 777,000 people each day depend on commuter rail services operated under contract by Amtrak, or that use Amtrak-owned infrastructure, shared operations and dispatching; an average of 69,000 people ride on up to 300 Amtrak trains each day. Amtrak relies on receiving federal subsidies in order to operate, although it continually working to become independent and profitable.

Although Amtrak's rates are not regulated, they do depend on the amount of subsidies received from the Federal government; this is not unlike most other forms of passenger rail in the U.S. Their only source of competition is other modes of transportation, and this also affects their rates. Fuel costs can dramatically affect rates and Amtrak’s need for subsidies; between 2004 and 2005, Amtrak’s fuel costs increased 149%, and continue to increase substantially. Despite an increase in passengers between 2004-2005 and improved fuel conservation methods that reduced their fuel consumption by nearly 10%, their fuel cost increased by $43 million.[57]

Amtrak is the sole large-scale provider of inter-city passenger transport. Their fleet includes 436 locomotives, of which 360 are diesel locomotives that used a reported 69.9[58] million of gallons of fuel in 2005, and 76 are electric locomotives. The FRA provided Amtrak with funding to purchase Acela locomotives, which are 4,000 horsepower gas turbine locomotives. These trains consume about the same amount of fuel as a diesel locomotive but produce about 1/10th of the NO_x

They offer service to 46 states on 21,000[59] miles of routes, only 745 miles of which are actually owned by Amtrak, primarily in Michigan, and between Boston and Washington DC.[60] Based on gross revenue, Amtrak is classified as a Class I railroad by the STB. However, unlike the Class I freight railroads, Amtrak's current operating expenses exceed its gross revenue.

The average age of a passenger train from Amtrak is quite young, in fact, since 1980 it has remained under 14.5 years old. Amtrak was on-time 74% of the time in 2003, but the 65% of that delay was caused by a host railroad. A host railroad is a freight or commuter railroad over which Amtrak operates on for all or part of a trip, and delays can include signal delays, train interference, routing delays or power outages. Amtrak must pay these host railroads for their use of this track and any other resources, in 2005, those payments were for more than 25 million train miles (one train-mile is a mile of track usage by each train) which totaled more than $92 million.

The average Amtrak/intercity fair was $55.15, the average revenue per passenger-mile is $0.249 for Amtrak, and the average length of haul was 231 miles[61] In 2006, Amtrak was able to obtain an additional subsidy in order to remain operational in 2006, in the amount of $1.1 billion[62], but the future of Amtrak may change if the Passenger Rail Reform Act is passed, this bill is currently in the House Subcommittee on Railroads, and would split Amtrak up into three different entities, two privately owned and one government corporation.

1.2.3.6.2 Commuter[63]

There are also 21 independent commuter rail systems operating in 16 U.S. cities, consuming 72 million gallons of diesel fuel annually, operating over 6,785 miles of track. They employed approximately 25,000 employees in 2004. Many of these commuter railroads rely on Federal subsidies to improve their infrastructure, in some cases they also rely on state and local government subsidies to support their operations.

The average length of haul for commuter rail in 2004 was 23.5 miles, an average of 414 million people use commuter rail each year to result in over 9.7 billion passenger-miles. The average commuter rail fair in 2004 was $3.90, with an average $0.154 revenue per passenger-mile. The commuter rail is also a young fleet and has remained younger than 17 years old since 1985.

1.2.4 Existing Regulations

1.2.4.1 Safety

Achieving and maintaining the safe operation of commercial (common carrier) railroads in the U.S. falls under the jurisdiction of the Federal Railroad Administration (FRA), which is a part of the Department of Transportation. The FRA was created in 1966 to perform a number of disparate functions, including rehabilitating Northeast Corridor rail passenger service, supporting research and development for rail transportation, and promoting and enforcing safety regulations throughout the railway system.

FRA safety regulations apply to railroads on a nationwide basis. In 49 CFR section 229 the regulations require safety inspections of each locomotive used in commercial operations: daily, every 92 days (i.e. the periodic inspection), annually, and biennial. Each inspection increases in complexity. The inspections are usually performed by the railroad which owns or leases the locomotive. FRA personnel review the findings of these inspections and any corrective actions identified and taken. Since each locomotive is required to be out of revenue service for inspection every 92 days, railroads commonly schedule their performance of preventive maintenance at these times. It appears likely that each locomotive is out of service for 12 to 24 hours during each FRA safety inspection and preventative maintenance period.[J] To limit the time that locomotives are out of service for these safety inspections and preventive maintenance, railroads maintain suitable facilities distributed across the nation. Thus, it appears that the railroads have had a long history of compliance with federal regulations, and have developed strategies to live within the regulations and to minimize any adverse business impacts that may have resulted.

1.2.4.2 Federal

In 1980 Congress passed the Staggers Act (USCA 49 § 10101) which laid out the government's statutory objectives for the Railroad Industry which are to balance the efficiency and viability of the industry with the need for: reasonable rates, fair wages, public health and safety, and energy conservation.

The railroads are governed by two separate Federal Agencies directly, both under the Department of Transportation, a cabinet-level department. The Federal Railroad Administration (FRA) regulates safety issues. The FRA sets safety standards for rail equipment and operation, and also investigates accidents on rail lines and at rail crossings. The FRA also plays a role in labor disputes to a small degree, by monitoring the progress of negotiations, projecting the economic impact of a strike and assisting the Secretary in briefing Congress if necessary. The STB is an adjudicatory body that was formed in 1966 to settle disputes and regulate the various modes of surface transportation within the U.S. Organizationally, the STB is part of the Department of Transportation (DOT), the STB deals with railway rate and service issues, railway restructuring and various other issues, including classification of railroads. The Surface Transportation Board (STB) regulates economic issues such as rates. The STB can also mandate access to locations in order to maintain competition in areas where mergers reduced the number of available carriers

1.2.4.3 Rates

Rail transportation accounts for 8.7% of all for-hire transportation services that are a measured in the GDP, or 0.2% of the total U.S. GDP. The average freight revenue per ton-mile for Class I rail in 2004 was $0.0235, and average operating revenue of $40.5 billion. Freight rates adjusted for inflation have declined by an average of 1.1% a year between 1990 and 2004 due in large part to the passage of the Staggers Act, as shown in Figure 1-15.[64]

[J] Values are an approximate estimate by FRA personnel.

If a shipper believes a rate is unreasonable (only if that shipper does not have access to another railroad, and waterway or highway modes are not feasible), they can complain to the STB, which has a stand-alone rate standard. This means that they determine what a hypothetical new carrier to serve that shipper would need to charge to cover all of its costs including capital and construction. Complaints such as these are typically made by bulk shippers, such as coal or chemicals, who cannot use other modes of transportation such as highway or can't access other railroads.

Figure 1-15 Railroad Rate Trends Before and After Staggers Act of 1980[64]

Sources: U.S. Dept. of Labor, Bureau of Labor Statistics, Producer Price Index of Line-Haul Operating Railroads; U.S. Dept. of Commerce, Bureau of Economic Analysis, Implicit Price Deflator for Gross Domestic Product

1.2.5 Foreign Railroads in US

Locomotives that operate extensively within the U.S. are subject to the existing provisions of 40 CFR Part 92.

1.2.5.1 Mexico

In 2004, the BTS says there were a total of 675,305 US/Mexico railcar crossings, that's an average of almost 1900 crossings a day, or one every minute. The Mexican Railroads and 16,415 miles of track have been privately owned since a Constitutional amendment was passed in 1995 (FRA "Border Issues"). They primarily haul NAFTA generated goods, such as cars, automobile parts, and other manufactured products. Mexico has two railroads, Ferrocarril Mexicano, which has a joint venture with UP and Transportacion Ferroviaria Mexicana (TFM) of which Kansas City Southern has controlling interest.

1.2.5.2 Canada

In 2004, the BTS says there were 1,950,909 border crossings into Canada by railcars. Canada is also home to two Class I railroads that operate extensively in the U.S., Grand Trunk Corporation which includes almost all of Canadian National's (CN) U.S. operations, and Canadian Pacific Railway which operates its Soo Line primarily in the U.S.

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CHAPTER 2: Air Quality and Resulting Health and Welfare Effects of Air Pollution from Mobile Sources

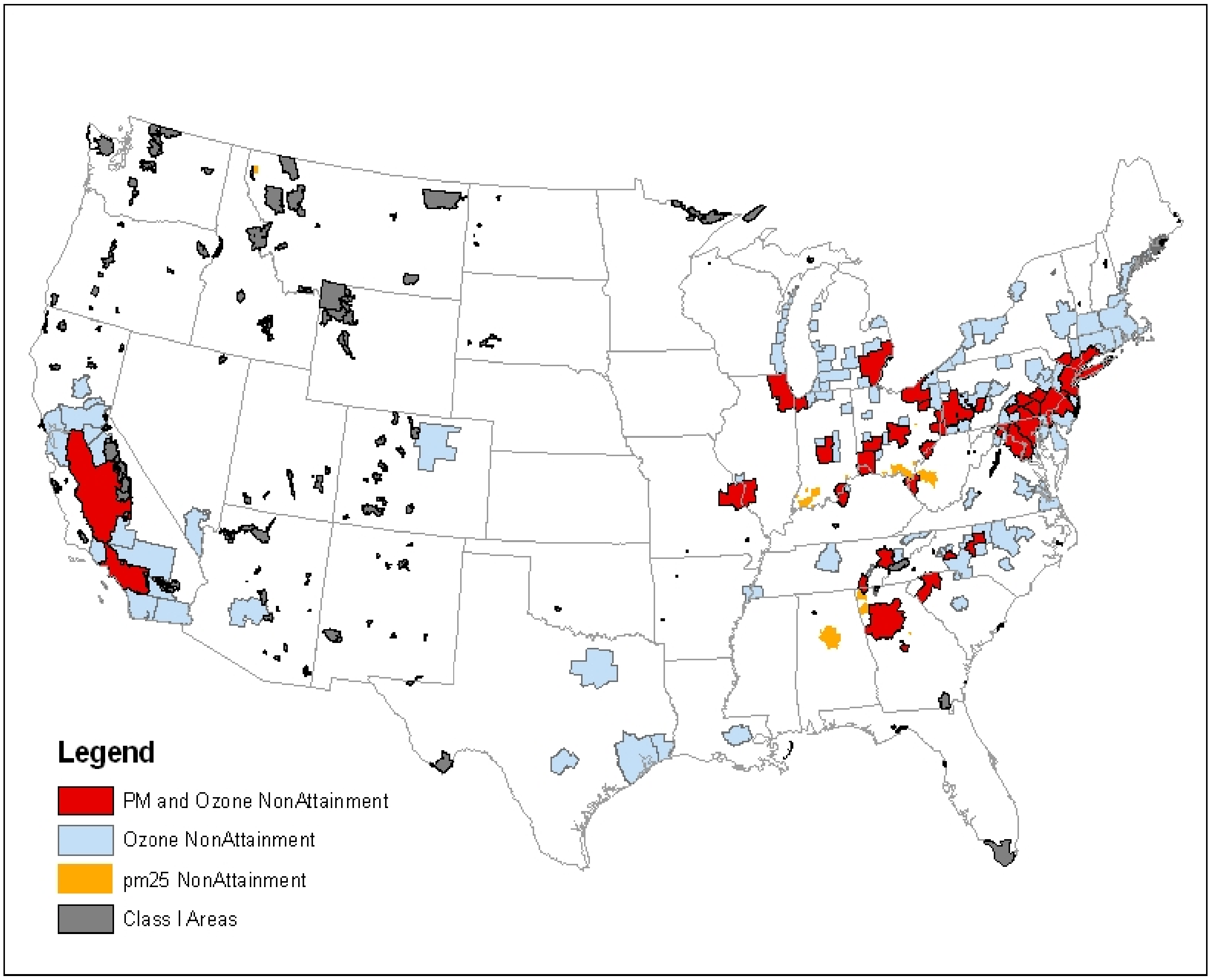
Locomotive and marine diesel engines subject to today's proposal generate significant emissions of particulate matter (PM) and nitrogen oxides (NO_x) that contribute to nonattainment of the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ and ozone. These engines also emit hazardous air pollutants or air toxics which are associated with serious adverse health effects. Emissions from locomotive and marine diesel engines also cause harm to public welfare and contribute to visibility impairment and other harmful environmental impacts across the US. Therefore, EPA is proposing to adopt new standards to control these emissions.

The health and environmental effects associated with these emissions are a classic example of a negative externality (an activity that imposes uncompensated costs on others). With a negative externality, an activity's social cost (the cost borne to society imposed as a result of the activity taking place) exceeds its private cost (the cost to those directly engaged in the activity). In this case, as described in this chapter, emissions from locomotives and marine diesel engines and vessels impose public health and environmental costs on society. However, these added costs to society are not reflected in the costs of those using these engines and equipment. The market system itself cannot correct this externality because firms in the market are rewarded for minimizing their production costs, including the costs of pollution control. In addition, firms that may take steps to use equipment that reduces air pollution may find themselves at a competitive disadvantage compared to firms that do not. To correct this market failure and reduce the negative externality from these emissions, it is necessary to give producers the market signals for the social costs generated from the emissions. The standards EPA is proposing will accomplish this by mandating that locomotives and marine diesel engines reduce their emissions to a technologically feasible limit. In other words, with this proposed rule the costs of the transportation services produced by these engines and equipment will reflect social costs more efficiently.

Today millions of Americans continue to live in areas with unhealthful air quality that may endanger public health and welfare (i.e., levels not requisite to protect the public health with an adequate margin of safety). With regard to $PM_{2.5}$ nonattainment, EPA recently finalized $PM_{2.5}$ nonattainment designations (70 FR 943, Jan 5, 2005) and as of October 2006 there are 88 million people living in 39 areas (which include all or part of 208 counties) that either do not meet the $PM_{2.5}$ NAAQS or contribute to violations in other counties. These numbers do not include the people living in areas where there is a significant future risk of failing to maintain or achieve the $PM_{2.5}$ NAAQS. Currently, ozone concentrations exceeding the level of the 8-hour ozone NAAQS occur over wide geographic areas, including most of the nation's major population centers. As of October 2006 there are approximately 157 million people living in 116 areas (461 full or partial counties) designated as not in attainment with the 8-hour ozone NAAQS. These numbers do not include the people living in areas where there is a future risk of failing to maintain or achieve the 8-hour ozone NAAQS. Figure 2-1 illustrates the widespread nature of these problems highlighting counties which are currently designated in nonattainment for the 8-hour ozone, $PM_{2.5}$

NAAQS, or for both pollutants. It also shows the location of mandatory class I federal areas for visibility.

Figure 2.1-1 Air Quality Problems are Widespread (October 2006)



Emissions from locomotive and marine diesel engines account for substantial portions of today's ambient $PM_{2.5}$ and NO_x levels [20 percent of total mobile source NO_x emissions and 25 percent of total mobile source diesel PM $_{2.5}$ emissions]. Over time, the relative contribution of these engines to air quality problems will increase unless EPA takes action to reduce their pollution levels. By 2030 locomotive and marine diesel engines could constitute more than 65 percent of mobile source diesel $PM_{2.5}$ emissions and 35 percent of mobile source NO_x emissions.

Under today's proposed comprehensive standards annual NO_x emissions would be reduced by more than 765,000 tons and annual $PM_{2.5}$ emissions by about 28,000 tons in

2030**.** We estimate that the reduced $PM_{2.5}$ levels would produce nationwide air quality improvements. According to air quality modeling performed in conjunction with this proposed rule, if finalized, all current $PM_{2.5}$ nonattainment areas would experience a resulting decrease in their 2020 and 2030 $PM_{2.5}$ design values (DV). In addition, all 116 monitored mandatory class I federal areas would also experience improved visibility. For the current 39 $PM_{2.5}$ nonattainment areas (annual DVs greater than 15µg/m^3) the average population weighted modeled future-year annual $PM_{2.5}$ DVs would on *average* decrease by 0.06 µg/m^3 in 2020 and by 0.14 µg/m^3 in 2030. The *maximum* decrease for future-year annual $PM_{2.5}$ DVs in these nonattainment areas would be 0.35µg/m^3 in 2020 and 0.90µg/m^3 in 2030.

This rule would also result in ozone benefits in 2030 for 114 of the current 116 ozone nonattainment areas. According to air quality modeling performed for this rulemaking, the proposed locomotive and marine diesel engine emissions controls are expected to provide nationwide improvements in ozone levels. On a population-weighted basis, the average modeled future-year 8-hour ozone design values would decrease by 0.29 ppb in 2020 and 0.80 ppb in 2030. Within projected ozone nonattainment areas, the average decrease would be somewhat higher: -0.30 ppb in 2020 and - 0.88 ppb in 2030.[A] The *maximum* decrease for future-year DVs over the U.S. would be -1.10 ppb in 2020 and -2.90 ppb in 2030

While EPA has already adopted many emission control programs that are expected to reduce both ambient ozone and PM levels, including the Clean Air Interstate Rule (CAIR) (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), the additional $PM_{2.5}$ and NO_x emissions reductions resulting from this locomotive and marine diesel engine rule would be important to states' efforts in attaining and maintaining the Ozone and $PM_{2.5}$ NAAQS near term and in the decades to come.

2.1 Particulate Matter

In this section we review the health and welfare effects of $PM_{2.5}$. We also describe air quality monitoring and modeling data that indicate many areas across the country continue to be exposed to high levels of ambient $PM_{2.5}$. Emissions of hydrocarbons (HCs) and NO_x from the engines subject to this proposed rule contribute to these PM concentrations. Information on air quality was gathered from a variety of sources, including monitored PM concentrations, air quality modeling done for recent EPA rulemakings and other state and local air quality information.

[A] 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 predicted in our modeling, but these results make clear that the overall effect of the proposed rule is positive. The two nonattainment areas that show slight increases in 2030 as a result of the rule are Los Angeles / South Coast Air Basin (0.1 ppb) and Norfolk-Virginia Beach-Newport News (0.8 ppb)

2.1.1 Science of PM Formation

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 is further described by breaking it down into size fractions. PM_{10} refers to particles generally less than or equal to 10 micrometers (µm). $PM_{2.5}$ refers to fine particles, those particles generally less than or equal to 2.5 µm in diameter. Inhalable (or "thoracic") coarse particles refer to those particles generally greater than 2.5 µm but less than or equal to 10 µm in diameter. Ultrafine PM refers to particles less than 100 nanometers (0.1 µm). Larger particles tend to be removed by the respiratory clearance mechanisms, whereas smaller particles are deposited deeper in the lungs.

Particles span many sizes and shapes and consist of hundreds of different chemicals. Particles are emitted directly from sources and are also formed through atmospheric chemical reactions; the former are often referred to as "primary" particles, and the latter as "secondary" particles. In addition, there are also physical, non-chemical reaction mechanisms that contribute to secondary particles. Particle pollution also varies by time of year and location and is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from particles' ability to shift between solid/liquid and gaseous phases, which is influenced by concentration and meteorology, especially temperature.

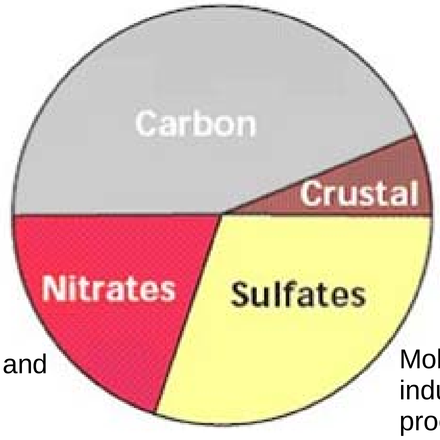
Particles are made up of different chemical components. The major chemical components include carbonaceous materials (carbon soot and organic compounds), and inorganic compounds including, sulfate and nitrate compounds that usually include ammonium, and a mix of substances often apportioned to crustal materials such as soil and ash (Figure 2-2). The different components that make up particle pollution come from specific sources and are often formed in the atmosphere. As mentioned above, particulate matter includes both "primary" PM, which is directly emitted into the air, and "secondary" PM. Primary PM consists of carbonaceous materials (soot and accompanying organics)—emitted from cars, trucks, heavy equipment, forest fires, some industrial processes and burning waste—and both combustion and process related fine metals and larger crustal material from unpaved roads, stone crushing, construction sites, and metallurgical operations. Secondary PM forms in the atmosphere from gases. Some of these reactions require sunlight and/or water vapor. Secondary PM includes:

Sulfates formed from sulfur dioxide emissions from power plants and industrial facilities;

Nitrates formed from nitrogen oxide emissions from cars, trucks, industrial facilities, and power plants; and

Organic carbon formed from reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees.

Figure 2-2 National Average of Source Contribution to Fine Particle Levels



Cars, trucks, industrial combustion and processes, heavy equipment, wildfires, wood/waste burning,

Suspended soils, industrial metallurgical operations

Cars, trucks, industrial combustion, and power generation

Mobile power generation, industrial combustion and processes

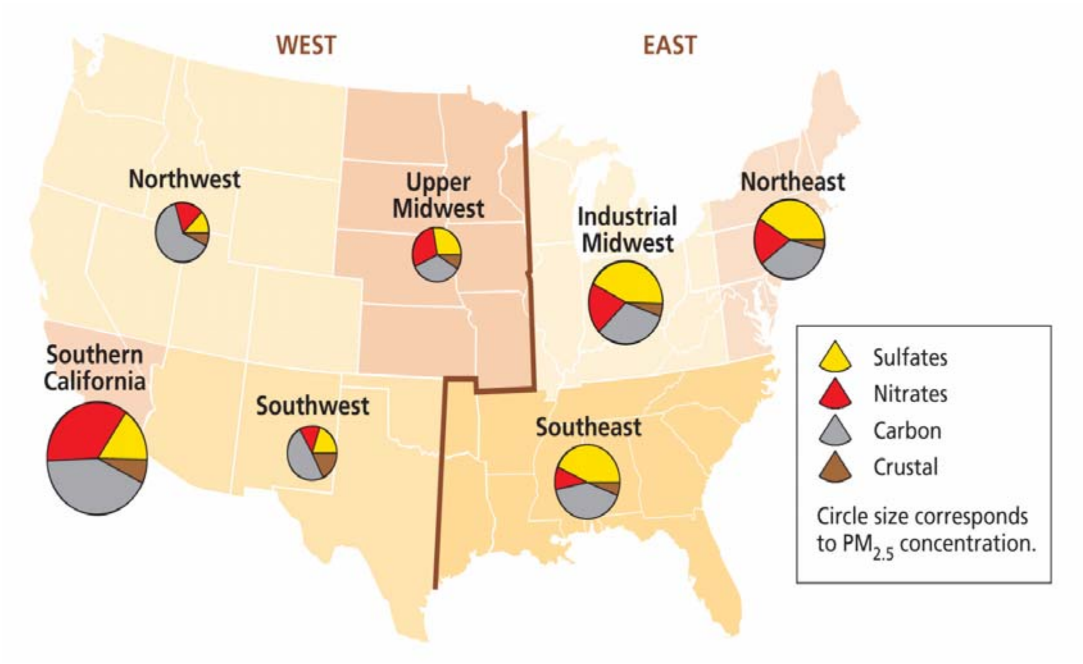
Source: The Particulate Matter Report, USEPA 454-R-04-002, Fall 2004. Carbon reflects both organic carbon and elemental carbon. Organic carbon accounts for emissions from a wide range of sources including locomotive and marine diesel engines as well as automobiles, biogenic, gas-powered off-road vehicles, and wildfires. Elemental carbon is formed from both diesel and gasoline powered sources.

2.1.1.1 Composition of $PM_{2.5}$ in Selected Urban Areas

Note that fine particles can be transported long distances by wind and weather and can be found in the air thousands of miles from where they formed. The relative contribution of various chemical components to $PM_{2.5}$ varies by region of the country, as illustrated in Figure 2-3. Data on $PM_{2.5}$ composition are available from the EPA Speciation Trends Network and the IMPROVE Network, 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 NO_x also play a major role in the western U.S., especially in the California area where nitrates are 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 $PM_{2.5}$ in 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 sulfate makes greater contribution than carbonaceous $PM_{2.5}$.

Figure 2-3 Average $PM_{2.5}$ Composition in Urban areas by Region, 2003



2.1.1.2 Regional and Local Source Contributions to Formation of $PM_{2.5}$

Both local and regional sources contribute to particle pollution. Figure 2-4 shows how much of the $PM_{2.5}$ mass can be attributed to local versus regional sources for 13 selected urban areas. The urban excess is estimated by subtracting the measured $PM_{2.5}$ species at a regional monitor location [B] assumed to be representative of regional background) from those measured at an urban location.

As shown in Figure 2-4, we observe a large urban excess across the U.S. for most $PM_{2.5}$ species but especially for total carbon mass. All of these locations have consistently high urban excess for total carbon mass with Fresno, CA and Birmingham, AL having the

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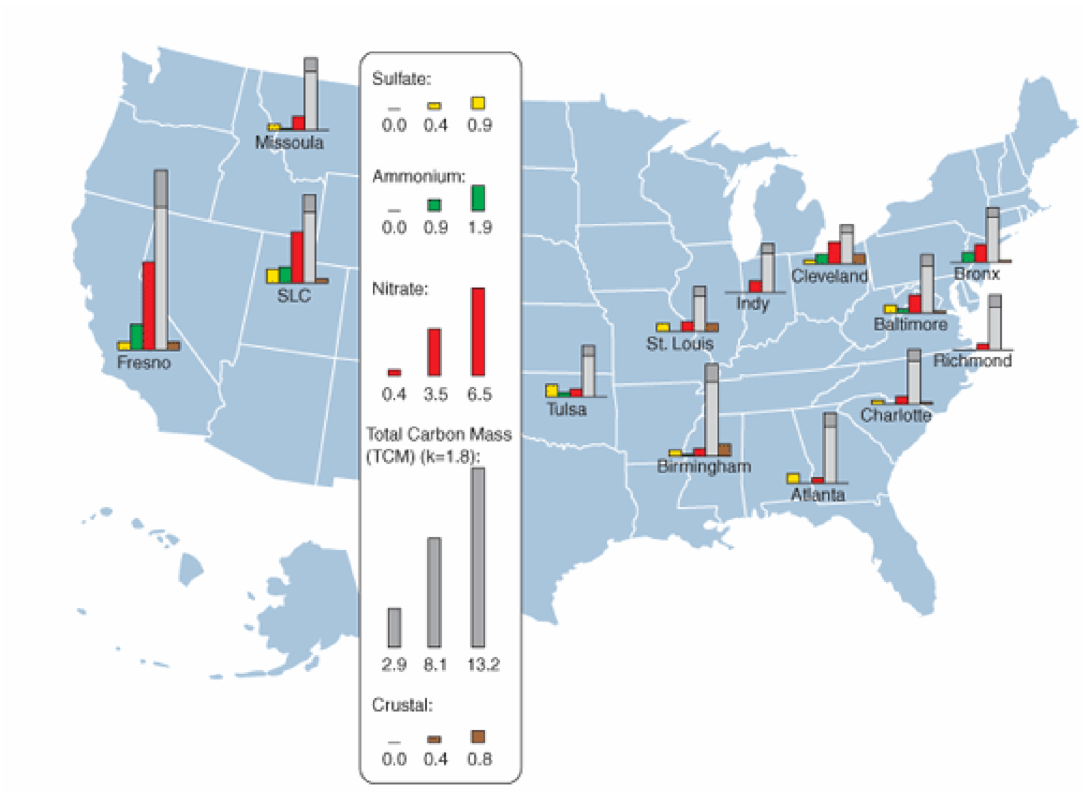
[B] Regional concentrations are derived from the rural IMPROVE monitoring network Interagency Monitoring of Protected Visual Environments. See http://vista.cira.colostate.edu/improve.

largest observed measures. Larger urban excess of nitrates is seen in the western U.S. with Fresno, CA and Salt Lake City, UT significantly higher than all other areas across the nation. These results indicate that local sources of these pollutants are indeed contributing to the $PM_{2.5}$ air quality problem in these areas.

Urban and nearby rural $PM_{2.5}$ concentrations suggest substantial regional contributions to fine particles in the East. The measured $PM_{2.5}$ concentration is not necessarily the maximum for each urban area. As expected for a predominately regional pollutant, only a modest urban excess is observed for sulfates

Figure 2-4. Estimated "Urban Excess" of 13 Urban Areas by $PM_{2.5}$ Species Component



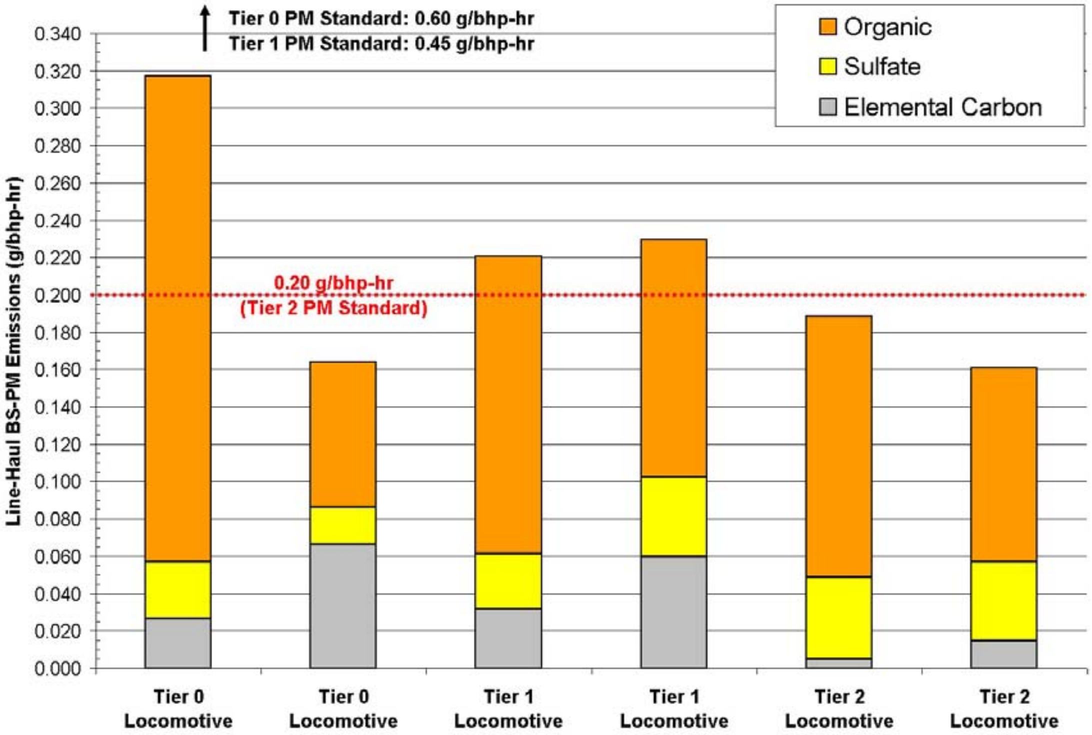
Note: Total Carbon Mass (TCM) is the sum of Organic Carbon (OC) and Elemental Carbon (EC). In this graph, the light grey is OC and the dark grey is EC. See: Turpin, B. and H-J, Lim, 2001: Species contributions to $PM_{2.5}$ mass concentrations: Revisiting common assumptions for estimating organic mass, Atmospheric Environment, 35, 602-610.

In the East, regional pollution contributes more than half of total $PM_{2.5}$ concentrations. Rural background $PM_{2.5}$ concentrations are high in the East and are somewhat uniform over large geographic areas. These regional concentrations come from emission sources such as power plants, natural sources, and urban pollution and can be transported hundreds of miles and reflect to some extent the denser clustering of urban areas in the East as compared to the West. The local and regional contributions for the major chemical components that make up urban $PM_{2.5}$ are sulfates, carbon, and nitrates.

2.1.1.3 Composition of $PM_{2.5}$ in Locomotive and Marine Diesel Engines

Locomotive and Marine Diesel engines contribute significantly to ambient $PM_{2.5}$ levels, largely through emissions of carbonaceous $PM_{2.5}$. As discussed in the previous section, carbonaceous $PM_{2.5}$ is a major portion of ambient $PM_{2.5}$, especially in populous urban areas. For the medium speed diesel engine commonly used in locomotive and Category 2 marine applications, the majority of the total carbon PM is organic carbon. Locomotive and marine diesels also emit high levels of NO_x which react in the atmosphere to form secondary $PM_{2.5}$ (namely ammonium nitrate). Locomotive and marine diesel engines also emit SO_2 and HC which form secondary $PM_{2.5}$ (namely sulfates and organic carbonaceous $PM_{2.5}$). Figure 2-5 shows the relative contribution of elemental and organic carbon to PM emissions for six Tier 0, Tier 1, and Tier 2 locomotives (three locomotive engines were 2-stroke while 3 locomotive engines were 4- stroke). This recent data, while limited to six locomotives, suggest that locomotives, regardless of when it was built, tend to emit a very high level of organic carbon PM precisely the type of carbon that appears to be responsible for a high percentage of the urban excess $PM_{2.5}$ species across the US.

Figure 2-5: PM emissions for 6 locomotives tested using 3000 ppm sulfur nonroad diesel fuel.



The proposed locomotive and marine engine standards would reduce emissions of carbonaceous PM. NO_x emissions, a prerequisite for formation of secondary nitrate aerosols, would also be reduced. The proposed standards would also reduce VOC emissions. The emission inventories are discussed in detail in Chapter 3 for primary $PM_{2.5}$ emissions from these sources. This proposed rule would also reduce secondary PM produced from these engines emissions.

As discussed in Sections 2.2 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 locomotive and marine 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 much 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 Health Effects of PM Pollution

As stated in the EPA Particulate Matter Air Quality Criteria Document (PM AQCD), available scientific findings “demonstrate well that human health outcomes are associated with ambient PM.”[C] We are relying on the data and conclusions in the PM AQCD and PM staff paper, which reflects EPA’s analysis of policy-relevant science from the PM AQCD, regarding the health effects associated with particulate matter.[1,2] We also present additional recent studies published after the cut-off date for the PM AQCD.[D][3] Taken together this information supports the conclusion that PM-related emissions such as those controlled in this action are associated with adverse health effects. Information on PM-related mortality and morbidity is presented first, followed by information on near-roadway exposure studies, marine ports and rail yard exposure studies.

[C] Personal exposure includes contributions from many different types of particles, from many sources, and in many different environments. Total personal exposure to PM includes both ambient and nonambient components; and both components may contribute to adverse health effects.

[D] These additional studies are included in the 2006 Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. The provisional assessment did not and could not (given a very short timeframe) undergo the extensive critical review by EPA, CASAC, and the public, as did the PM AQCD. The provisional assessment found that the “new” studies expand the scientific information and provide important insights on the relationship between PM exposure and health effects of PM. The provisional assessment also found that “new” studies generally strengthen the evidence that acute and chronic exposure to fine particles and acute exposure to thoracic coarse particles are associated with health effects.

2.1.2.1 Short-term Exposure Mortality and Morbidity Studies

As discussed in the PM AQCD, short-term exposure to $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases (PM AQCD, p. 8-305), hospitalization and emergency department visits for cardiopulmonary diseases (PM AQCD, p. 9-93), increased respiratory symptoms (PM AQCD, p. 9-46), decreased lung function (PM AQCD Table 8-34) and physiological changes or biomarkers for cardiac changes (PM AQCD, Section 8.3.1.3.4). In addition, the PM AQCD describes a limited body of new evidence from epidemiologic studies for potential relationships between short term exposure to PM and health endpoints such as low birth weight, preterm birth, and neonatal and infant mortality. (PM AQCD, Section 8.3.4).

Among the studies of effects from short-term exposure to $PM_{2.5}$, several studies specifically address the contribution of mobile sources to short-term $PM_{2.5}$ effects on daily mortality. These studies indicate that there are statistically significant associations between mortality and PM related to mobile source emissions (PM AQCD, p.8-85). The analyses incorporate source apportionment tools into daily mortality studies and are briefly mentioned here. Analyses incorporating source apportionment by factor analysis with daily time-series studies of daily death indicated a relationship between mobile source $PM_{2.5}$ and mortality.[4,5] Another recent study in 14 U.S. cities examined the effect of PM_{10} exposures on daily hospital admissions for cardiovascular disease. 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.[6] These studies provide evidence that PM-related emissions, specifically from mobile sources, are associated with adverse health effects.

In terms of morbidity, short-term studies have shown associations between ambient $PM_{2.5}$ and cardiovascular and respiratory hospital admissions (PM AQCD, p. 9-93), decreased lung function (PM AQCD Table 8-34), and physiological cardiac changes (PM AQCD, Section 8.3.1.3.4).

2.1.2.2 Long-term Exposure Mortality and Morbidity Studies

Long-term exposure to elevated ambient $PM_{2.5}$ is associated with mortality from cardiopulmonary diseases and lung cancer (PM AQCD, p. 8-307), and effects on the respiratory system such as decreased lung function or the development of chronic respiratory disease (PM AQCD, pp. 8-313, 8-314). Of specific importance to this proposal, the PM AQCD also notes that the PM components of gasoline and diesel engine exhaust represent one class of hypothesized likely important contributors to the observed ambient PM-related increases in lung cancer incidence and mortality (PM AQCD, p. 8-318).

The PM AQCD and PM Staff Paper emphasize the results of two long-term studies, the Six Cities and American Cancer Society (ACS) prospective cohort studies, based on several factors – the inclusion of measured PM data, the fact that the study populations were similar to the general population, and the fact that these studies have undergone extensive reanalysis (PM AQCD, p. 8-306, Staff Paper, p.3-18).[7,8,9] These studies indicate that there are significant associations for all-cause, cardiopulmonary, and lung cancer mortality with long-term exposure to $PM_{2.5}$. One analysis of a subset of the ACS cohort data, which was published after the PM AQCD was finalized but in time for the 2006 Provisional Assessment, found a larger association than had previously been reported between long-term $PM_{2.5}$ exposure and mortality in the Los Angeles area using a new exposure estimation method that accounted for variations in concentration within the city.[10]

As discussed in the PM AQCD, the morbidity studies that combine the features of cross-sectional and cohort studies provide the best evidence for chronic exposure effects. Long-term studies evaluating the effect of ambient PM on children's development have shown some evidence indicating effects of $PM_{2.5}$ and/or PM_{10} on reduced lung function growth (PM AQCD, Section 8.3.3.2.3). In another recent publication included in the 2006 Provisional Assessment, investigators in southern California reported the results of a cross-sectional study of outdoor $PM_{2.5}$ and measures of atherosclerosis in the Los Angeles basin.[11] The study found significant associations between ambient residential $PM_{2.5}$ and carotid intima-media thickness (CIMT), an indicator of subclinical atherosclerosis, an underlying factor in cardiovascular disease.

2.1.2.3 Roadway-Related Exposure and Health Studies

A recent body of studies reinforces the findings of these PM morbidity and mortality effects by looking at traffic-related exposures, PM measured along roadways, or time spent in traffic and adverse health effects. While many of these studies did not measure PM specifically, they include potential exhaust exposures which include mobile source PM because they employ indices such as roadway proximity or traffic volumes. One study with specific relevance to $PM_{2.5}$ health effects is a study that was done in North Carolina looking at concentrations of $PM_{2.5}$ inside police cars and corresponding physiological changes in the police personnel driving the cars. The authors report significant elevations in markers of cardiac risk associated with concentrations of $PM_{2.5}$ inside police cars on North Carolina state highways.[12] A number of studies of traffic-related pollution have shown associations between fine particles and adverse respiratory outcomes in children who live near major roadways.[13,14,15]

2.1.2.4 Marine Ports and Rail Yard Studies

Recently, new studies from the State of California provides evidence that $PM_{2.5}$ emissions within marine ports and rail yards contribute significantly to elevated ambient concentrations near these sources[16] and that a substantial number of people experience exposure to fresh locomotive and marine diesel engine emissions, raising potential health concerns. Additional information on near roadway, marine port, and rail yard emissions and potential health effects can be found in Section 2.3.1.4 of this draft RIA.

2.1.3 Attainment and Maintenance of the $PM_{2.5}$ NAAQS

EPA has recently amended the NAAQS for $PM_{2.5}$ (71 FR 61144, October 17, 2006). The final rule, signed on September 21, 2006 and published on October 17, 2006, addressed revisions to the primary and secondary NAAQS for PM to provide increased protection of public health and welfare, respectively. The primary $PM_{2.5}$ NAAQS include a short-term

(24-hour) and a long-term (annual) standard. The level of the 24-hour $PM_{2.5}$ NAAQS has been revised from 65µg/$m^3$to 35 µg/m^3 to provide increased protection against health effects associated with short-term exposures to fine particles. The current form of the 24-hour $PM_{2.5}$ standard was retained (e.g., based on the 98th percentile concentration averaged over three years). The level of the annual $PM_{2.5}$ NAAQS was retained at 15µg/m^3, continuing protection against health effects associated with long-term exposures. The current form of the annual $PM_{2.5}$ standard was retained as an annual arithmetic mean averaged over three years, however, the following two aspects of the spatial averaging criteria were narrowed: (1) the annual mean concentration at each site shall be within 10 percent of the spatially averaged annual mean, and (2) the daily values for each monitoring site pair shall yield a correlation coefficient of at least 0.9 for each calendar quarter.

With regard to the secondary $PM_{2.5}$ standards, EPA has revised these standards to be identical in all respects to the revised primary standards. Specifically, EPA has revised the current 24-hour $PM_{2.5}$ secondary standard by making it identical to the revised 24-hour $PM_{2.5}$ primary standard and retained the annual $PM_{2.5}$ secondary standard. This suite of secondary $PM_{2.5}$ standards is intended to provide protection against PM-related public welfare effects, including visibility impairment, effects on vegetation and ecosystems, and material damage and soiling.

The proposed emission reductions from this rule would assist $PM_{2.5}$ nonattainment areas in reaching the standard by each area's respective attainment date and assist $PM_{2.5}$ maintenance areas in maintaining the $PM_{2.5}$ standards in the future. The emission reductions will also help continue to lower ambient PM levels and resulting health impacts into the future. In this section we present information on current and future $PM_{2.5}$ levels.

2.1.3.1 Current $PM_{2.5}$ Air Quality

A nonattainment area is defined in the Clean Air Act (CAA) as an area that is violating an ambient standard or is contributing to a nearby area that is violating the standard. In 2005, EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS based on air quality design values (using 2001-2003 or 2002-2004 measurements) and a number of other factors.[E](70 FR 943, January 5, 2005; 70 FR 19844, April 14, 2005). These areas are comprised of 208 full or partial counties with a total population exceeding 88 million. The 1997 $PM_{2.5}$ nonattainment counties, areas and populations, as of October 2006, are listed in Appendix 2A to this RIA. The 1997 $PM_{2.5}$ NAAQS was recently revised and the 2006 $PM_{2.5}$ NAAQS became effective on December 18, 2006. Nonattainment areas will be designated with respect to the 2006 $PM_{2.5}$ NAAQS in early 2010.

As can be seen in Figure 2-1 ambient $PM_{2.5}$ levels exceeding the 1997 $PM_{2.5}$ NAAQS are widespread throughout the country. States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Most $PM_{2.5}$ nonattainment areas will be required to attain the 1997 $PM_{2.5}$ NAAQS in the 2010 to 2015

[E] The full details involved in calculating a $PM_{2.5}$ design value are given in Appendix N of 40 CFR Part 50.

time frame and then be required to maintain the 1997 $PM_{2.5}$ NAAQS thereafter.[F] The attainment dates associated with the potential nonattainment areas based on the 2006 $PM_{2.5}$ NAAQS would likely be in the 2015 to 2020 timeframe. The emission standards being proposed in this action would become effective between 2008 and 2017. The expected $PM_{2.5}$ and $PM_{2.5}$ precursor inventory reductions from the standards being proposed in this action will be needed by states to attain or maintain the $PM_{2.5}$ NAAQS.

Table 2-1 provides an estimate of the counties violating the 2006 $PM_{2.5}$ NAAQS based on 2003-05 air quality data. The areas designated as nonattainment for the 2006 PM2.5 NAAQS will be based on three years of air quality data from later years. Also, the county numbers in the summary table include only the counties with monitors violating the 2006 PM2.5 NAAQS. The monitored county violations may be an underestimate of the number of counties and populations that will eventually be included in areas with multiple counties designated nonattainment. Currently more than 106 million people live in counties where monitors show violation of the 2006 standards.

Table 2-1 Counties violating the 2006 $PM_{2.5}$ NAAQS based on 2003-2005 Air Quality Data

Fine Particle Standards: Current Nonattainment Areas and Other Violated Counties		
	Number of Counties	Population
1997 $PM_{2.5}$ Standards: 39 areas currently designated	208	88,394,000
2006 $PM_{2.5}$ Standards: Counties with violating monitors	49	18,198,676
Total	**257**	**106,592,676**

2.1.3.2 Current and Projected Composition of Urban $PM_{2.5}$ for Selected Areas

Based on CMAQ modeling for the new PM NAAQS standard, a local perspective of $PM_{2.5}$ levels and composition was developed by EPA to elaborate further on the nature of the $PM_{2.5}$ air quality problem after implementation of the CAIR/CAMR/CAVR rules, the national mobile rules for light and heavy-duty vehicles and nonroad mobile sources, and current state programs that were on the books as of early 2005.[17] As an illustrative example, the PM NAAQS RIA developed a localized analysis of current ambient and future-year speciation for two cities, one in the East (Detroit) and one in the West (Salt Lake City).[18]

Figure 2-6 shows projected $PM_{2.5}$ component species concentrations (i.e., sulfate, nitrate, elemental carbon, organic aerosols, crustal, and uncontrollable $PM_{2.5}$) for current ambient data (5 year weighted average, 1999–2003) and a 2020 regulatory base case with the

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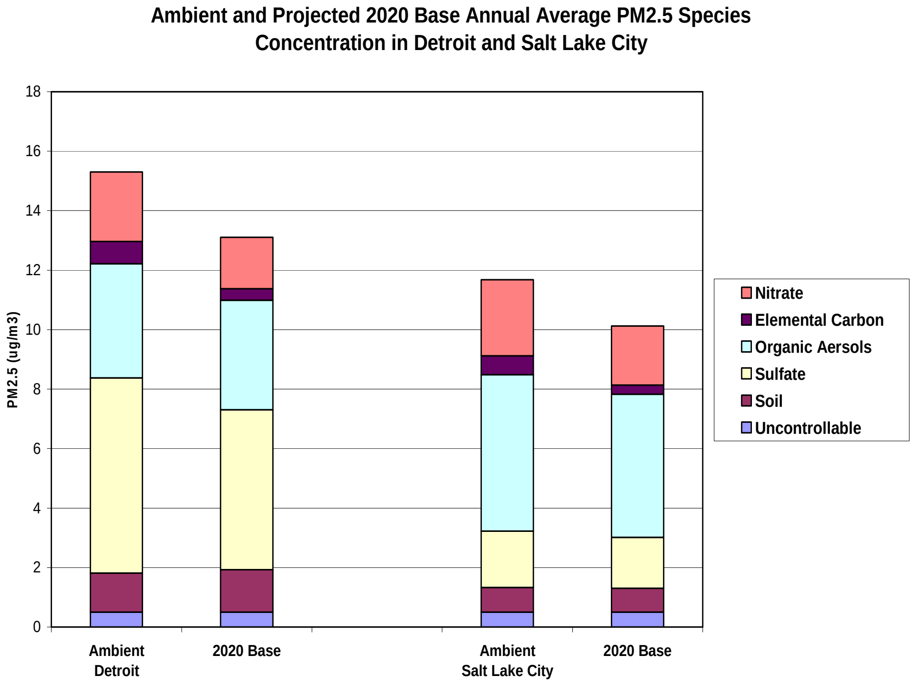
[F] The EPA finalized $PM_{2.5}$ attainment and nonattainment areas in April 2005. The EPA finalized the PM Implementation rule in Nov. 5, 2005, 70 FR 65984).

addition of the controls mentioned in the previous paragraph. Note that organic aerosols include directly emitted organic carbon and organic carbon particles formed in the atmosphere from anthropogenic sources and biogenic sources. Uncontrollable $PM_{2.5}$ is based upon a 0.5 µg/m^3 $PM_{2.5}$ blank mass correction used in the Speciated Modeled Attainment Test (SMAT) approach, in which a number of adjustments and additions were made to the measured species data to provide for consistency with the chemical components retained on the FRM Teflon filter.[19] The analysis provided here specifically looks at one area in the East (Detroit), and one in the West (Salt Lake City).

Figure 2-6. Base Case and Projected $PM_{2.5}$ Component Species Concentrations in Detroit and Salt Lake City



Note: The ambient and projected 2020 base case annual design values above are averages taken across multiple urban area monitors. Thus, while the average 2020 Detroit base case design value reflected above is lower than the projected base case design values at certain Detroit monitors.

Notably, organic aerosols constitute a large fraction of the overall remaining $PM_{2.5}$ mass in Detroit and Salt Lake City. Sulfate is a considerable part of the total $PM_{2.5}$ mass in both cities and is the largest contributor to $PM_{2.5}$ mass in Detroit. Nitrate is a relatively small source of $PM_{2.5}$ for Detroit but nitrate is the second largest contributor to the remaining $PM_{2.5}$ problem in Salt Lake City; the exception is that on higher days, nitrate represents the largest contributor in Salt Lake City. The relatively large contribution of sulfate to $PM_{2.5}$ mass in

Detroit is characteristic of the urban air pollution mixture in the East, while the nitrate contribution to $PM_{2.5}$ mass in Salt Lake City is characteristic of that found in the West.

2.1.4 Source Apportionment Studies of $PM_{2.5}$

Determining sources of fine particulate matter is complicated in part because the concentrations of various components are influenced by both primary emissions and secondary atmospheric reactions. As described earlier, when attempting to characterize the sources affecting $PM_{2.5}$ concentrations, it is important to note that both regional and local sources impact ambient levels. In the eastern US, regional fine particles are often dominated by secondary particles including sulfates, organics (primary and secondary) and nitrates. These are particles which form through atmospheric reactions of emitted sulfur dioxide, oxides of nitrogen and ammonia, and are transported over long distances. Conversely, local contributions to fine particles are likely dominated by directly emitted particulate matter from sources such as gasoline and diesel mobile sources, including locomotive and marine diesel engines[20], industrial facilities (e.g., iron and steel manufacturing, coke ovens, or pulp mills), and residential wood and waste burning.

Development of effective and efficient emission control strategies to lower $PM_{2.5}$ ambient concentrations can be aided by determining the relationship between the various types of emissions sources and elevated levels of $PM_{2.5}$ at ambient monitoring sites. Source apportionment analyses such as receptor modeling are useful in this regard by both qualifying and quantifying potential fine particulate regional and local source impacts on a receptor's ambient concentrations. The goal is to apportion the mass concentrations into components attributable to the most significant sources. Receptor modeling techniques are observation-based models which utilize measured ambient concentrations of $PM_{2.5}$ species to quantify the contribution that regional and local sources have at a given receptor which, in this case, is an ambient monitoring location. [21] These techniques are very useful in characterizing fine particulate source contributions to ambient $PM_{2.5}$ levels; however, there are inherent limitations including but not limited to the adequacy (e.g., vintage and representativeness) of existing source profiles in identifying source groups or specific sources, availability and completeness of ambient datasets to fully inform these techniques, and current scientific understanding and measured data to relate tracer elements to specific sources, production processes, or activities. Additionally, commingling of similar species from different sources in one "factor" can make it difficult to relate the "factor" to a particular source.

A literature compilation summarizing source apportionment studies was conducted as part of a research and preparation program for the CAIR (EPA, 2005) rule, which was focused on $PM_{2.5}$ transport.[22] Literature selected in this compilation represented key source apportionment research, focusing primarily on recent individual source apportionment studies in the eastern U.S. The sources identified are grouped into seven categories: secondary sulfates, mobile, secondary nitrates, biomass burning, industrial, crustal and salt, and other/not identified. Some of these studies are based on older ambient databases and more recent ambient data have shown improvement and reduced levels of ambient $PM_{2.5}$ concentrations across the U.S., especially in the East, which affects the quantitative conclusions one may draw from these studies. Notably, the relative fraction of sulfates has continued to decrease with the implementation of the acid rain program and removal of sulfur from motor vehicle fuels. More routine monitoring for specific tracer compounds that are unique to individual sources can lead to better separation of blended “factors” such as secondary commingled sulfates and organic aerosols which are more attributed to emissions from vehicles and vegetation. Western studies have focused on sources impacting both high population areas such as Seattle, Denver, the San Joaquin Valley, Los Angeles, San Francisco as well as national parks.[23,24,25,26,27,28,29,30,31,32] More routine monitoring for specific tracer compounds that are unique to individual sources can lead to better separation of blended “factors” such as secondary commingled sulfates and organic aerosols which are more attributed to emissions from vehicles and vegetation.

As mentioned previously, the sources of $PM_{2.5}$ can be categorized as either direct emissions or contributing to secondary formation. The results of the studies showed that approximately 20 to 60% of the fine particle mass comes from secondarily formed nitrates and sulfates depending on the area of the country, with nitrates predominantly affecting the West, sulfates in the East and a mixture of the two in the Industrial Midwest.

The precursors of these particles are generally gaseous pollutants such as sulfur dioxide or oxides of nitrogen, which react with ammonia in the atmosphere to form ammonium salts. Dominant sources of SO_2 include power generation facilities, which, are also sources of NO_x along with mobile sources including locomotive and marine diesel engines. The result of recent and future reductions in precursor emissions from electrical generation utilities and mobile sources, however, will lead to a reduction in precursor contributions which would aid in limiting the production of secondary sulfates and nitrates. Also, reductions in gasoline and diesel fuel sulfur will reduce mobile source SO_2 emissions.

In addition, secondary organic carbon aerosols (SOA) also make a large contribution to the overall total $PM_{2.5}$ concentration in both the Eastern and Western United States. For many of the receptor modeling studies, the majority of organic carbon is attributed to mobile source emissions (including both gasoline and diesel). While vehicles emit organic carbon particulate, the various organic gases also emitted by these sources react in the atmosphere to form SOA which shows a correlation to the other secondarily formed aerosols due to common atmospheric reactions. As section 2.1.1.3 of this RIA discusses, based on current data, locomotives and larger marine diesel engines which have similar engine characterizations emit a relatively large amount of organic PM. Other common sources of the organic gases which form SOA include vegetation, vehicles, and industrial VOC and SVOC emissions. However, due to some limits on data and a lack of specific molecular markers, current receptor modeling techniques have some difficulty attributing mass to SOA. Therefore, currently available source apportionment studies may be attributing an unknown amount of SOA in ambient PM to direct emissions of mobile sources; concurrently, some secondary organic aerosol found in ambient samples may, as mentioned above, be coming from mobile sources and not be fully reflected in these assessments. Research is underway to improve estimates of the contribution of SOA to total fine particulate mass.

While gaseous precursors of $PM_{2.5}$ are important contributors, urban primary sources still influence peak local concentrations that exceed the NAAQS, even if their overall contributions are smaller. The mixture of industrial source contributions to mass vary across the nation and include emissions from heavy manufacturing such as metal processing (e.g., steel production, coke ovens, foundries), petroleum refining, and cement manufacturing, among others. Other sources of primary $PM_{2.5}$ are more seasonal in nature. One such source is biomass burning, which usually contributes more during the winter months when households burn wood for heat, but also contributes episodically during summer as a result of forest fires. Other seasonal sources of primary PM include soil, sea salt and road salting operations that occur in winter months. The extent of these primary source contributions to local $PM_{2.5}$ problems varies across the U.S. and can even vary within an urban area. The key for individual areas is to understand the nature of the problem (i.e., determining the relationship between various types of emissions sources and elevated levels of $PM_{2.5}$ at ambient monitoring) in order to develop effective and efficient emission control strategies to reduce $PM_{2.5}$ ambient concentrations through local control program scenarios

2.1.5 Risk of Future Violations

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into compliance in the future. Based on the final rule designating and classifying 1997 $PM_{2.5}$ nonattainment areas, most of these areas will be required to attain the 1997 $PM_{2.5}$ NAAQS in the 2009 to 2014 time frame and then be required to maintain the $PM_{2.5}$ NAAQS thereafter.

As mentioned in Section 2.1.3, the 1997 $PM_{2.5}$ NAAQS was recently revised (71 FR 61144, October 17, 2006) and the 2006 NAAQS, effective on December 18, 2006, revised the level of the 24-hour $PM_{2.5}$ standard to 35 $\mu g/m^3$ from the old standards of 65 $\mu g/m^3$ and retained the level of the annual $PM_{2.5}$ standard at 15 $\mu g/m^3$.[33] The nonattainment areas will be designated with respect to the 2006 PM NAAQS in early 2010. The attainment dates associated with the potential new $PM_{2.5}$ nonattainment areas would likely be in the 2015 to 2020 timeframe. The emission standards being proposed in this action will become effective between 2008 and 2017 and it is anticipated that the expected $PM_{2.5}$ inventory reductions from the standards being proposed will be useful to states seeking to attain or maintain both the 1997 $PM_{2.5}$ NAAQS as well as the 2006 PM standards.

Even with the implementation of all current state and federal regulations, including the CAIR Rule, the NO_x SIP call, nonroad and on-road diesel rules and the Tier 2 rule, there are projected to be U.S. counties violating the $PM_{2.5}$ NAAQS well into the future. EPA modeling conducted as part of the final PM NAAQS rule projects that in 2015, with all current controls in effect, up to 52 counties, with a population of 53 million people, may not attain some combination of the annual standard of 15 $\mu g/m^3$ and the daily standard of 35 $\mu g/m^3$, and that even in 2020 up to 48 counties with a population of 54 million people may still not be able to attain either the annual, daily, or both the annual and daily $PM_{2.5}$ standards.[34] This does not account for additional areas that have air quality measurements within 10 percent of the 2006 $PM_{2.5}$ standard. These areas, although not violating the standards, would also benefit from the emissions reductions being proposed, ensuring long term maintenance of the PM NAAQS. For example, in 2015, an additional 27 million people are projected to live in 54 counties that have air quality measurements within 10 percent of the 2006 PM NAAQS. In 2020, 25 million people, in 50 counties, will continue to have air quality measurements within 10 percent of the revised standards. The expected $PM_{2.5}$

reductions from this proposed in this action will be needed by states to both attain and maintain the $PM_{2.5}$ NAAQS. [35]

States and state organizations have told EPA that they will need the reductions proposed in this proposed rule in order to be able to attain or maintain the 1997 $PM_{2.5}$ standards as well as necessary to attain the 2006 $PM_{2.5}$ NAAQS.[36]

In conjunction with this rulemaking, we performed a series of $PM_{2.5}$ air quality modeling simulations for the continental U.S. The model simulations were performed for five emissions scenarios:

(1) 2001/2002 baseline projection,

(2) 2020 baseline projection,

(3) 2020 projection with locomotive/marine diesel engine controls,

(4) 2030 baseline projection, and

(5) 2030 projection with locomotive/marine diesel engine controls.

Further discussion of this modeling, including evaluations of model performance relative to predicted future air quality, occur in section 2.1.5.2 of this RIA and also in the AQ Modeling TSD.

The model outputs from the2001/2002, 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 excedence areas which would require additional emission reductions to attain and maintain the $PM_{2.5}$ NAAQS. The impacts of the locomotive/marine diesel engine 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 are a substantial number of counties across the US projected to experience $PM_{2.5}$ concentrations at or above the $PM_{2.5}$ NAAQS in 2020 and 2030. Emission reductions from locomotive and marine diesel engines will be helpful for these counties in attaining and maintaining the $PM_{2.5}$ NAAQS.

2.1.5.1 Air Quality Modeling Results for $PM_{2.5}$

According to air quality modeling performed for this rulemaking, the proposed locomotive and marine diesel engine standards are expected to provide nationwide improvements in $PM_{2.5}$ levels. On a population-weighted basis, the average modeled future-year annual $PM_{2.5}$ design value for all counties is expected to decrease by 0.06 $\mu g/m^3$ in 2020 and 0.13 $\mu g/m^3$ in 2030. In counties predicted to have annual design values greater than 15 $\mu g/m^3$ the average decrease would be somewhat higher**:** 0.16 $\mu g/m^3$ in 2020 and 0.36 $\mu g/m^3$ in 2030. In addition, those counties that are within 10 percent of the annual $PM_{2.5}$ design value would see their average DV decrease by 0.06 $\mu g/m^3$ in 2020 and 0.23 $\mu g/m^3$ in 2030. The maximum decrease for future-year annual $PM_{2.5}$ design values in 2020 would be

0.35µg/m^3 and 0.90µg/m^3 in 2030. Note that for the current 39 $PM_{2.5}$ nonattainment areas the average population weighted modeled future-year annual $PM_{2.5}$ design values would on *average* decrease by 0.06µg/m^3 in 2020 and by 0.14 µg/m^3 in 2030.

The geographic impact of the proposed locomotive and marine diesel engine controls in 2030 on annual $PM_{2.5}$ design values (DV) in counties across the US, can be seen in Figure 2-7. A complete set of maps illustrating the geographic impact of various alternatives explored as part of this rulemaking are available in Air Quality Modeling TSD for this rulemaking.

Figure 2-7 Impact of Proposed Locomotive/Marine controls on annual $PM_{2.5}$ Design Values (DV) in 2030

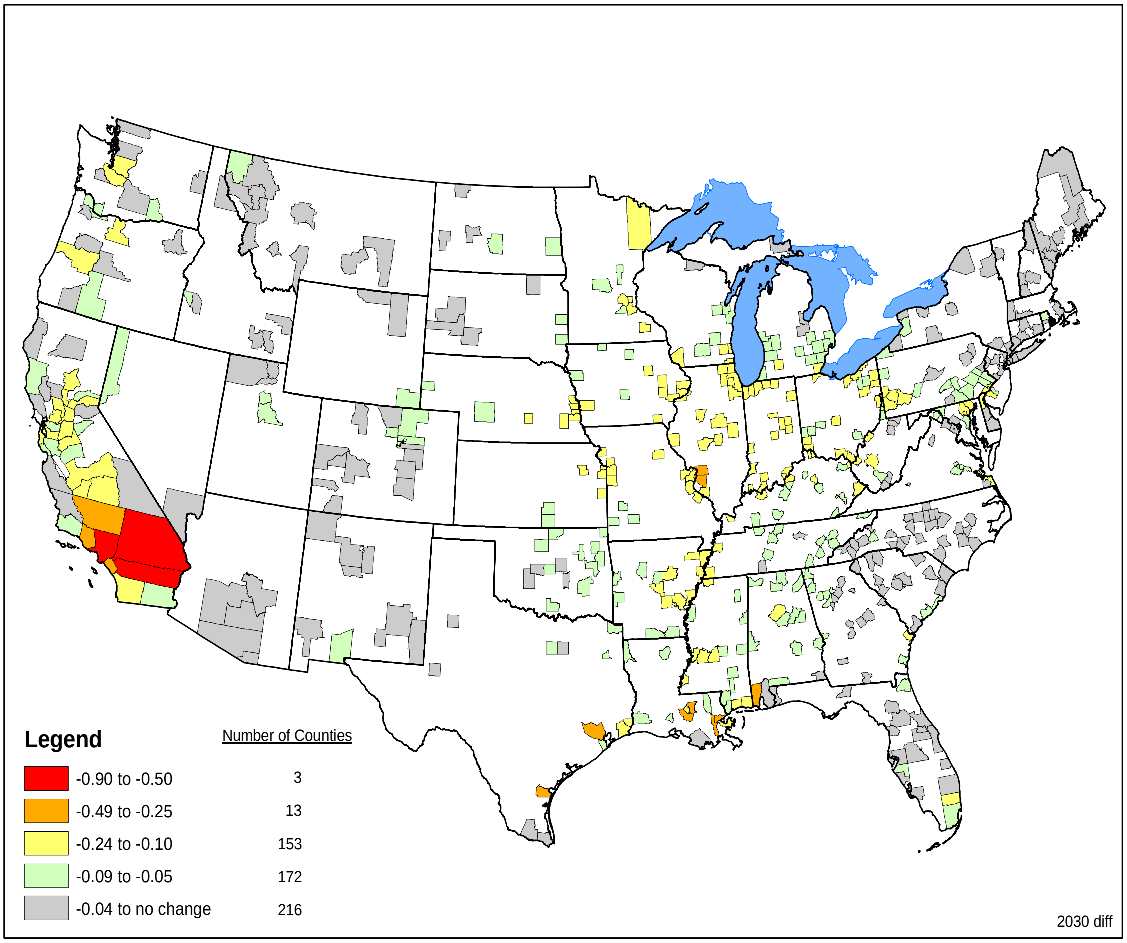


Figure 2-7 illustrates that the greatest emission reductions in 2030 are projected to occur in Southern California where three counties would experience reductions in their $PM_{2.5}$ design values of -0.50 to -0.90 μg/m^3. The next level of emission reductions would occur among 13 counties geographically dispersed along the Gulf Coast, near St. Louis, and again Southern California. An additional 325 counties spread across the US would see a decrease in $PM_{2.5}$ DV ranging from -0.05 to -0.24 μg/m^3.

Table 2-2 lists the counties with 2020 and 2030 projected annual $PM_{2.5}$ design values that violate the annual standard or are within 10 percent of it. Counties are marked with a "V" in the table if their projected design values are greater than or equal to 15.05 μg/m^3 . Counties are marked with an "X" in the table if their projected design values are greater than or equal to 13.55 μg/m^3, but less than 15.05 μg/m^3. 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. The current 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 2-2 Counties with 2020 and 2030 Projected Annual $PM_{2.5}$Design Values in Violation or within 10 percent of the Annual $PM_{2.5}$ Standard. In the Base and Control cases.

State	County	1999 – 2003 Average Design Value (μg/m^3)	2020		2030		2000 Population
			Base	Control	Base	Control	
AL	Jefferson	19.05	V	V	V	V	662,046
CA	Fresno	21.85	V	V	V	V	799,406
CA	Imperial	15.22	X	X	X	X	142,360
CA	Kern	22.74	V	V	V	V	661,644
CA	Kings	18.52	V	V	V	V	129,460
CA	Los Angeles	24.21	V	V	V	V	9,519,334
CA	Merced	16.73	V	V	V	V	210,553
CA	Orange	20.39	V	V	V	V	2,846,288
CA	Riverside	28.82	V	V	V	V	1,545,386
CA	San Bernardino	25.27	V	V	V	V	1,709,433
CA	San Diego	16.44	X	X	V	X	2,813,831
CA	San Joaquin	15.46	V	V	V	V	563,597

CA	Stanislaus	17.87	V	V	V	V	446,996
CA	Tulare	23.06	V	V	V	V	368,020
GA	Bibb	16.42	X	X	X	X	153,887
GA	Clayton	17.51	X	X	X	X	236,516
GA	Floyd	16.67	X	X	X	X	90,565
GA	Fulton	19.51	V	V	V	V	816,005
IL	Cook	18.00	V	V	V	V	5,376,739
IL	Madison	17.40	V	X	V	V	258,940
IL	St. Clair	16.87	X	X	X	X	256,081
KY	Jefferson	17.07	X		X	X	693,603
MI	Wayne	19.62	V	V	V	V	2,061,161
MT	Lincoln	16.24	X	X	X	X	18,837
NY	New York	16.67	X	X	X	X	1,537,194
OH	Cuyahoga	19.25	V	V	V	V	1,393,977
OH	Hamilton	18.55	X	X	X	X	845,302
OH	Jefferson	18.36	X	X	X	X	73,894
OH	Scioto	19.53	V	V	V	V	79,195
PA	Allegheny	21.17	V	V	V	V	1,281,665
PA	Philadelphia	16.39			X	X	1,517,549
TX	Harris	14.13			X	X	3,400,577
WV	Cabell	17.22			X		96,784
WV	Kanawha	17.75	X	X	X	X	200,072

2.1.5.2 PM Air Quality Modeling and Methods

2.1.5.2.1 *Air Quality Modeling Overview*

A national scale air quality modeling analysis was performed to estimate future year annual and daily $PM_{2.5}$ concentrations and visibility. These projections were used as inputs to the calculation of expected benefits from the locomotive and marine emissions controls considered in this assessment. The 2001-based CMAQ modeling platform was used as the tool for the air quality modeling of future baseline emissions and control scenarios. In addition to the CMAQ model, the modeling platform includes the emissions, meteorology, and initial and boundary condition data which are inputs to this model. The CMAQ model is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary particulate matter concentrations and deposition over regional and urban spatial scales (e.g., over the contiguous U.S.).[37] [38] [39] 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 pollution control measures that affect PM, ozone and deposition of pollutants to the surface.

The CMAQ model was peer-reviewed in 2003 for EPA as reported in “Peer Review of CMAQ Model”.[40] The latest version of CMAQ (Version 4.5) was employed for this modeling analysis. This version reflects updates in a number of areas to improve the underlying science and address comments from the peer-review including (1) use of a state-of-the-science inorganic nitrate partitioning module (ISORROPIA) and updated gaseous, heterogeneous chemistry in the calculation of nitrate formation, (2) a state-of-the-science secondary organic aerosol (SOA) module that includes a more comprehensive gas-particle partitioning algorithm from both anthropogenic and biogenic SOA, (3) an in-cloud sulfate chemistry module that accounts for the nonlinear sensitivity of sulfate formation to varying pH, and (4) an updated CB-IV gas-phase chemistry mechanism and aqueous chemistry mechanism that provide a comprehensive simulation of aerosol precursor oxidants.[41]

2.1.5.2.2 *Model Domain and Configuration*

As shown in Figure 2-8 the CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico (Figure 2.1-6). The domain extends from 126 degrees to 66 degrees west longitude and from 24 degrees north latitude to 52 degrees north latitude. The horizontal grid cells are approximately 36 km by 36 km. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 mb.

Figure 2-8. Map of the CMAQ modeling domain.

2.1.5.2.3 *Model Inputs*

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from a simulation of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model[42] for the entire year of 2001. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. For this analysis, version 3.6.1 of MM5 was used. The horizontal domain consisted of a single 36 x 36 km grid with 165 by 129 cells, selected to maximize the coverage of the ETA model analysis region and completely cover the CMAQ modeling domain with some buffer to avoid boundary effects. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.1 to derive the specific inputs to CMAQ: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[43]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[44] The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2001 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the CMAQ simulations.

A complete description of the development and processing of model-ready meteorological inputs and initial and boundary condition inputs used for this analysis are discussed in the CAIR TSD.[45] In addition, the development of the gridded, hourly model-ready emissions inputs used for the 2001 base year and each of the future year base cases and control scenarios are summarized above in Chapter 2.

2.1.5.2.4 *CMAQ Evaluation*

An operational model performance evaluation for $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.) was conducted using the 2001 data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. In summary, model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region.[46] The "acceptability" of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies[47]. Overall, the performance for this application is within the range or better than these other applications. A detailed summary of the 2001 CMAQ model performance evaluation is available within the PM NAAQS RIA, Appendix O.

2.1.5.2.5 *Model Simulation Scenarios*

As part of our analysis the CMAQ modeling system was used to calculate daily and annual $PM_{2.5}$ concentrations and visibility estimates for each of the following eleven emissions scenarios:

2001 base year

2020 base line projection 2020 with projection of impact of primary locomotive/marine control case, low control option, high control option, and a locomotive only control case

2030 base line projection

2030 with projection of impact of primary locomotive/marine control case, low control option, high control option, and a locomotive-only control case

We use the predictions from the model in a relative sense by combining the 2001 base-year predictions with predictions from each future-year scenario and speciated ambient air quality observations to determine $PM_{2.5}$ concentrations and visibility for each of the 2020 and 2030 scenarios. After completing this process, we then calculated daily and seasonal PM air quality metrics as inputs to the health and welfare impact functions of the benefits analysis. The following sections provide a more detailed discussion of our air quality projection method and a summary of the results.

2.1.5.2.6 *Projection Methodology for Annual Average Design Values*

The procedures used to project the annual design values are generally consistent with the projection techniques used in the Clean Air Interstate Rule (CAIR). The projected annual design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses an FRM mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the US. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$).

More complete details of the SMAT procedures used in the CAIR analysis can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)".[48] For this latest analysis, several datasets and techniques were updated. The changes and updates include:

1) Revised database of $PM_{2.5}$ speciation data which includes data from 2002 and 2003.

2) Revised interpolations of $PM_{2.5}$ species data using updated techniques.

3) An updated equation to calculate particle bound water.

4) Revised treatment of ambient ammonium data.

Documentation of these updates and changes can be found in “Procedures for Estimating Future $PM_{2.5}$ Values for the PM NAAQS Final Rule by Application of the Speciated Modeled Attainment Test (SMAT)" (EPA, 2006). [49] Below are the steps we followed for projecting future $PM_{2.5}$ concentrations. These steps were performed to estimate future case concentrations at each FRM monitoring site. The starting point for these projections is a 5 year weighted average design value for each site. The weighted average is calculated as the average of the 1999-2001, 2000-2002, and 2001-2003 design values at each monitoring site. By averaging 1999-2001, 2000-2002, and 2001-2003, the value from 2001 is weighted three times, whereas, values for 2000 and 2002 are each weighted twice, and 1999 and 2003 are each weighted once. This approach has the desired benefits of (1) weighting the $PM_{2.5}$ values towards the middle year of the five-year period (2001), which is the Base Year for our emissions projections, and (2) smoothing out the effects of year-to-year variability in emissions and meteorology that occurs over the full five-year period. This approach provides a robust estimate of current air quality for use as a basis for future year projections.

Step 1: Calculate quarterly mean ambient concentrations for each of the major components of $PM_{2.5}$ (i.e., sulfate, nitrate, ammonium, elemental carbon, organic carbon, water, and crustal material) using the component species concentrations estimated for each FRM site.

The component species concentrations were estimated using an average of 2002 and 2003 ambient data from speciation monitors. The speciation data was interpolated to provide estimates for all FRM sites across the country. The interpolated component concentration information was used to calculate species fractions at each FRM site. The estimated fractional composition of each species (by quarter) was then multiplied by the 5 year weighted average 1999-2003 FRM quarterly mean concentrations at each site (e.g., 20 percent sulfate multiplied by 15.0 $\mu g/m^3$ of $PM_{2.5}$ equals 3 $\mu g/m^3$ sulfate). The end result is a quarterly concentration for each of the $PM_{2.5}$ species at each FRM site.

Step 2: Calculate quarterly average Relative Reduction Factors (RRFs) for sulfate, nitrate, elemental carbon, organic carbon, and crustal material. The species-specific RRFs for the location of each FRM are the ratio of the 2015 (or 2020) future year cases to the 2001 Base Year quarterly average model predicted species concentrations. The species-specific quarterly RRFs are then multiplied by the corresponding 1999-2003 quarterly species concentration from Step 1. The result is the future case quarterly average concentration for each of these species for each future year model run.

Step 3: Calculate future case quarterly average concentrations for ammonium and particle-bound water. The future case concentrations for ammonium are calculated using the future case sulfate and nitrate concentrations determined from Step 2 along with the degree of neutralization of sulfate (held constant from the base year). Concentrations of particle-bound water are calculated using an empirical equation derived from the AIM model using the concentrations of sulfate, nitrate, and ammonium as inputs.

Step 4: Calculate the mean of the four quarterly average future case concentrations to estimate future annual average concentration for each component species. The annual average concentrations of the components are added together to obtain the future annual average concentration for $PM_{2.5}$.

Step 5: For counties with only one monitoring site, the projected value at that site is the future case value for that county. For counties with more than one monitor, the highest future year value in the county is selected as the concentration for that county.

2.1.6 Environmental Effects of PM Pollution

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

2.1.6.1 Visibility Impairment

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[50] Visibility impairment manifests in two principal ways: as local visibility impairment and as regional haze.[51] Local visibility impairment may take the form of a localized plume, a band or layer of discoloration appearing well above the terrain as a result from complex local meteorological conditions. Alternatively, local visibility impairment may manifest as an urban haze, sometimes referred to as a “brown cloud.” This urban haze is largely caused by emissions from multiple sources in the urban areas and is not typically attributable to only one nearby source or to long-range transport. The second type of visibility impairment, regional haze, usually results from multiple pollution sources spread over a large geographic region. Regional haze can impair visibility over large regions and across states.

Visibility is important because it has direct significance to people’s enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the PM AQCD as well as the 2005 PM Staff Paper.[52,53]

Fine particles are the major cause of reduced visibility in parts of the United States. To address the welfare effects of PM on visibility, EPA set secondary $PM_{2.5}$ standards which would work in conjunction with the establishment of a regional haze program. The secondary (welfare-based) $PM_{2.5}$ NAAQS was established as equal to the suite of primary (health-based) NAAQS. Furthermore, Section 169 of the Act provides additional authority to remedy existing visibility impairment and prevent future visibility impairment in the 156 national parks, forests and wilderness areas labeled as mandatory class I federal areas (62 FR 38680-81, July 18, 1997). These areas are defined in Section 162 of the Act as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977. In July 1999 the regional haze rule (64 FR 35714) was put in place to protect the visibility in mandatory class I federal areas. A list of the mandatory class I federal areas is included in Appendix 2D. Visibility can be said to be impaired in both $PM_{2.5}$ nonattainment areas and mandatory class I federal areas.

Control of locomotive and marine diesel engine emissions will improve visibility across the nation. The PM and NO_x emissions from locomotive and marine diesel engines subject to this proposed rule either directly emit $PM_{2.5}$ or contribute to formation of secondary PM-precursors and contribute to these visibility effects. This is evident in the $PM_{2.5}$ visibility modeling completed for this rulemaking. In this section we present current information and projected estimates about both visibility impairment related to ambient $PM_{2.5}$ levels across the country and visibility impairment in mandatory class I federal areas. We conclude that visibility will continue to be impaired in the future and the projected emission reductions from this proposed action will help improve visibility conditions across the country and in mandatory class I federal areas. More detailed discussions on visibility are contained in the EPA PM AQCD and the revised PM NAAQS rule RIA.[54, 55]

2.1.6.1.1 *Current Visibility Impairment*

The need for reductions in the levels of $PM_{2.5}$ is widespread. 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.[56]

As mentioned above the secondary $PM_{2.5}$ standards were set as equal to the suite of primary $PM_{2.5}$ standards. Recently designated $PM_{2.5}$ nonattainment areas indicate that almost 90 million people live in 208 counties that are in nonattainment for the 1997 $PM_{2.5}$ NAAQS, (see Appendix 2A for the complete list of current nonattainment areas). Thus, at least these populations (plus others who travel to these areas) would likely be experiencing visibility impairment.

As discussed in the Staff Paper (EPA 2004, section 6.2), in mandatory class I federal areas, visibility levels on the 20 percent haziest days in the West are about equal to levels on the 20 percent best days in the East. Despite improvement through the 1990's, visibility in the rural East remains significantly impaired, with an average visual range of approximately 20 km on the 20 percent haziest days (compared to the naturally occurring visual range in the eastern US of about 150 ±45km). In the rural West, the average visual range showed little change over this period, with an average visual range of approximately 100km on the 20 percent haziest days (compared to the naturally occurring visual range in the western US of about 230 ±40km).

In urban areas, visibility levels show far less difference between eastern and western regions. For example, the average visual ranges on the 20 percent haziest days in eastern and western urban areas are approximately 20 km and 27 km, respectively (Schmidt et al., 2005). Even more similarity is seen in considering 4-hour (12 to 4 pm.) average $PM_{2.5}$ concentrations for which the average visual ranges on the 20 percent haziest days in eastern and western urban areas are approximately 26 km and 31 km, respectively (Schmidt et al., 2005).

2.1.6.1.2 *Current Visibility Impairment at Mandatory Class I Federal Areas*

Detailed information about current and historical visibility conditions in mandatory class I federal areas is summarized in the EPA Report to Congress and the 2002 EPA Trends Report.[57,58] The conclusions draw upon the Interagency Monitoring of Protected Visual Environments (IMPROVE) network data. One of the objectives of the IMPROVE monitoring network program is to provide regional haze monitoring representing all mandatory class I federal areas where practical. The National Park Service report also describes the state of national park visibility conditions and discusses the need for improvement.[59]

The regional haze rule requires states to establish goals for each affected mandatory class I federal area that 1) improves visibility on the haziest days (20% most impaired days), 2) ensures no degradation occurs on the cleanest days (20% least impaired days), and 3) achieves natural background visibility levels by 2064. Although there have been general trends toward improved visibility, progress is still needed on the haziest days. Specifically, as discussed in the 2002 EPA Trends Report, without the effects of pollution a natural visual range in the United States is approximately 75 to 150 km in the East and 200 to 300 km in the West. In 2001, the mean visual range for the worst days was 29 km in the East and 98 km in the West. [60] Table 2-3 below provides the current visibility deciviews for each of the 116 monitored federal class 1 areas along with the natural background values for each area.

The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a “deciview”, which is used in the valuation of visibility. The deciview metric provides a 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.

2.1.6.1.3 *Future Visibility Impairment*

Additional emission reductions will be needed from a broad set of sources, including those proposed in this action, as part of the overall strategy to achieve the visibility goals of the Act and the regional haze program.

Modeling conducted for this proposed rule was used to project visibility conditions in 116 of the mandatory class I federal areas across the US in 2020 and 2030 as a result of the proposed locomotive and marine diesel standards. The results indicate that improvements in visibility would occur in all 116 mandatory class I federal areas, although all these areas would continue to have annual average deciview levels above background in both 2020 and 2030. Table 2-3 below indicates the current monitored deciview values, the natural background levels each area is attempting to reach, and also the projected deciview values in 2020 and 2030 with and without the proposed standards. In 2030, the greatest visibility improvement due to this proposed rule would occur at Agua Tibia (-0.24 deciview) located in San Diego County, California followed by San Georgonio (-0.22 deciview) in San Bernadino County, California.

Table 2-3 Current and Future projected Visibility Conditions With and Without Proposed Locomotive and Marine Diesel Rule in Mandatory Class I Federal Areas (Annual Average Deciview)

Annual Results		DeciViews[a]					
Site name	**state**	**1998-2002 Baseline Visibility (deciviews)**	**2020base case without controls**	**2020 base case with proposed controls**	**2030 base case without controls**	**2030 base case with proposed controls**	**Natural Background (deciviews)**
Acadia	ME	22.7	12.84	12.83	12.88	12.87	11.5
Agua Tibia	CA	23.2	16.03	15.94	15.98	15.74	7.2
Anaconda - Pintler	MT	18.0	7.53	7.52	7.53	7.51	7.9
Arches	UT	12.3	8.19	8.18	8.22	8.19	7.3
Badlands	SD	12.0	11.42	11.39	11.38	11.32	7.0
Bandelier	NM	17.3	8.63	8.62	8.66	8.63	7.3
Big Bend	TX	13.2	12.16	12.15	12.17	12.15	7.0
Black Canyon of the Gunnison	CO	18.4	6.84	6.83	6.83	6.81	6.9
Desolation	CA	11.6	7.63	7.61	7.59	7.55	7.1
Bob Marshall	MT	14.2	9.25	9.24	9.24	9.21	7.4
Boundary Waters Canoe Area	MN	20.0	12.06	12.04	12.10	12.04	11.2
Bryce Canyon	UT	11.5	7.53	7.51	7.53	7.51	7.1
Bridger	WY	27.6	6.98	6.97	6.97	6.95	11.3
Brigantine	NJ	12.0	18.49	18.46	18.61	18.55	7.0
Cabinet Mountains	MT	13.8	8.55	8.53	8.57	8.52	7.4
Caney Creek	AR	25.9	17.52	17.47	17.52	17.43	11.3
Canyonlands	UT	12.0	8.06	8.06	8.09	8.08	7.0
Caribou	CA	25.9	7.64	7.62	7.60	7.55	11.4
Carlsbad Caverns	NM	14.8	11.74	11.73	11.74	11.71	7.3
Chassahowitzka	FL	17.6	18.54	18.52	18.62	18.58	7.0
Chiricahua NM	AZ	25.7	8.60	8.59	8.59	8.57	11.5
Chiricahua W	AZ	13.9	8.60	8.59	8.59	8.57	6.9
Craters of the Moon	ID	13.9	8.74	8.72	8.71	8.66	6.9
Dome Land	CA	14.7	11.89	11.87	11.73	11.66	7.1
Dolly Sods	WV	12.9	16.79	16.77	16.84	16.80	7.1
Eagles Nest	CO	27.6	6.26	6.25	6.26	6.24	11.3
Emigrant	CA	20.3	9.50	9.49	9.41	9.37	7.1
Everglades	FL	19.6	14.33	14.32	14.40	14.38	7.3

Fitzpatrick	WY	11.3	6.98	6.97	6.97	6.95	7.1
Flat Tops	CO	17.6	6.32	6.31	6.33	6.31	7.1
Galiuro	AZ	20.3	8.58	8.57	8.58	8.55	11.2
Gates of the Mountains	MT	11.5	6.43	6.42	6.43	6.40	7.1
Gila	NM	11.3	8.20	8.19	8.20	8.18	7.1
Glacier	MT	13.9	12.38	12.32	12.40	12.29	6.9
Glacier Peak	WA	11.2	7.61	7.59	7.67	7.63	7.2
Grand Teton	WY	13.5	7.55	7.54	7.53	7.51	7.0
Great Gulf	NH	19.5	12.87	12.87	12.90	12.89	7.6
Great Sand Dunes	CO	14.0	8.52	8.51	8.51	8.50	7.8
Great Smoky Mountains	TN	12.1	18.16	18.12	18.19	18.11	7.1
Guadalupe Mountains	TX	23.2	11.76	11.74	11.76	11.72	11.3
Hells Canyon	OR	13.1	10.66	10.63	10.64	10.56	7.1
Isle Royale	MI	29.5	12.48	12.46	12.50	12.45	11.4
Jarbidge	NV	17.6	7.11	7.10	7.11	7.08	7.0
James River Face	VA	18.1	17.89	17.84	17.93	17.83	7.3
Joshua Tree	CA	21.1	12.35	12.30	12.34	12.20	11.2
Joyce Kilmer – Slickrock	NC	28.5	18.16	18.12	18.19	18.11	11.2
Kalmiopsis	OR	12.6	9.02	9.01	9.02	8.99	7.1
Kings Canyon	CA	19.5	16.46	16.44	16.36	16.30	7.1
Lava Beds	CA	29.5	8.21	8.18	8.18	8.12	11.5
La Garita	CO	14.8	7.19	7.18	7.19	7.18	7.7
Lassen Volcanic	CA	23.5	7.68	7.66	7.64	7.59	7.1
Linville Gorge	NC	11.6	16.84	16.80	16.87	16.80	7.1
Lostwood	ND	14.8	13.24	13.22	13.19	13.15	7.3
Lye Brook	VT	16.6	12.71	12.70	12.75	12.73	7.5
Mammoth Cave	KY	27.9	19.95	19.91	19.97	19.87	11.4
Marble Mountain	CA	19.6	9.13	9.11	9.09	9.04	7.3
Maroon Bells – Snowmass	CO	23.9	6.15	6.14	6.16	6.14	11.3
Mazatzal	AZ	30.2	9.38	9.37	9.43	9.40	11.5
Medicine Lake	MT	17.1	12.38	12.35	12.34	12.28	7.7
Mesa Verde	CO	11.3	8.16	8.15	8.18	8.16	7.1
Mingo	MO	13.1	19.15	19.09	19.15	19.02	6.9
Mission Mountains	MT	17.7	8.91	8.90	8.89	8.87	7.3
Mount Hood	OR	12.8	7.55	7.53	7.63	7.56	7.1
Mokelumne	CA	27.5	7.69	7.68	7.63	7.60	11.3
Moosehorn	ME	14.2	13.23	13.23	13.26	13.25	7.4
Mount Rainier	WA	12.9	10.31	10.28	10.37	10.30	7.1
Mount Jefferson	OR	21.4	8.21	8.20	8.25	8.20	11.4
Mount Washington	OR	14.0	8.31	8.29	8.36	8.32	7.8
Mount Zirkel	CO	15.7	7.70	7.69	7.72	7.70	7.8
North Cascades	WA	18.9	7.76	7.75	7.81	7.79	7.9
Okefenokee	GA	15.7	17.83	17.80	17.87	17.80	7.9
Otter Creek	WV	11.7	16.74	16.71	16.77	16.73	7.1
Pasayten	WA	14.0	7.67	7.65	7.67	7.62	7.8
Petrified Forest	AZ	26.4	8.54	8.50	8.55	8.48	11.5

Pine Mountain	AZ	27.6	9.30	9.29	9.29	9.26	11.3
Presidential Range – Dry	NH	14.7	12.61	12.61	12.66	12.66	7.8
Rawah	CO	13.5	7.55	7.54	7.55	7.53	7.0
Red Rock Lakes	WY	13.1	7.53	7.52	7.51	7.49	6.9
Redwood	CA	23.2	9.49	9.46	9.46	9.38	11.3
Cape Romain	SC	11.7	17.14	17.10	17.28	17.17	7.1
Rocky Mountain	CO	12.1	8.36	8.34	8.37	8.33	7.1
Roosevelt Campobello	ME	16.5	13.35	13.34	13.37	13.37	7.8
Salt Creek	NM	14.1	12.12	12.09	12.07	12.02	7.1
San Gorgonio	CA	21.4	13.72	13.63	13.65	13.43	11.4
San Jacinto	CA	17.7	13.33	13.22	13.12	12.85	7.0
San Pedro Parks	NM	21.5	7.20	7.19	7.20	7.18	7.1
Sawtooth	ID	21.5	8.49	8.48	8.48	8.46	7.1
Scapegoat	MT	11.4	9.09	9.07	9.08	9.06	7.0
Selway - Bitterroot	MT	13.6	7.53	7.51	7.54	7.48	7.2
Seney	MI	14.2	13.22	13.20	13.27	13.21	7.3
Sequoia	CA	12.3	15.96	15.93	15.73	15.66	7.3
Shenandoah	VA	23.8	16.26	16.23	16.27	16.20	11.4
Sierra Ancha	AZ	23.5	9.50	9.49	9.50	9.47	7.1
Sipsey	AL	27.6	19.15	19.10	19.16	19.06	11.3
Alpine Lakes	WA	13.4	10.92	10.88	11.03	10.92	6.9
South Warner	CA	28.7	8.31	8.29	8.27	8.23	11.4
Eagle Cap	OR	16.6	11.25	11.21	11.24	11.14	7.3
Strawberry Mountain	OR	19.6	11.35	11.33	11.34	11.28	7.5
Swanquarter	NC	14.7	16.39	16.37	16.43	16.39	6.9
Sycamore Canyon	AZ	24.6	10.71	10.66	10.72	10.64	11.2
Teton	WY	16.1	7.71	7.70	7.70	7.68	7.0
Theodore Roosevelt	ND	12.1	11.96	11.89	11.91	11.79	7.1
Three Sisters	OR	17.6	8.31	8.29	8.36	8.32	7.3
Superstition	AZ	14.8	9.89	9.87	9.86	9.84	7.3
Thousand Lakes	CA	15.7	7.68	7.66	7.64	7.59	7.9
UL Bend	MT	14.7	9.16	9.15	9.13	9.10	7.2
Upper Buffalo	AR	25.5	16.89	16.85	16.88	16.79	11.3
Voyageurs	MN	18.4	11.25	11.23	11.25	11.21	11.1
Weminuche	CO	11.6	6.90	6.89	6.89	6.88	7.1
West Elk	CO	11.3	6.18	6.17	6.19	6.17	7.1
Wind Cave	SD	16.0	9.56	9.52	9.55	9.47	7.2
Wolf Island	GA	26.4	18.14	18.11	18.18	18.13	11.4
Yellowstone	WY	12.1	7.69	7.67	7.67	7.65	7.1
Yolla Bolly - Middle Eel	CA	17.1	9.31	9.30	9.28	9.23	7.4
Yosemite	CA	17.6	9.30	9.28	9.21	9.17	7.1
Zion	UT	13.5	8.92	8.89	8.95	8.90	7.0

a) The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a "deciview", which is used in the valuation of visibility. The deciview metric provides a 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.

2.1.6.1.4 *Visibility Modeling Methodology*

The modeling platform described in Section 2.1.5 above was also used to project changes in visibility. The estimate of visibility benefits was based on the projected improvement in annual average visibility at mandatory class I federal areas. There are 156 Federally mandated Class I areas which, under the Regional Haze Rule, are required to achieve natural background visibility levels by 2064. These mandatory class I federal areas are mostly national parks, national monuments, and wilderness areas. There are currently 110 Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites (representing all 156 mandatory class I federal areas) collecting ambient $PM_{2.5}$ data at mandatory class I federal areas, but only 81 of these sites have complete data for 2001. For this analysis, we quantified visibility improvement at the 116 mandatory class I federal areas which have complete IMPROVE ambient data for 2001 or are represented by IMPROVE monitors with complete data.[G]

Visibility impairment is quantified in extinction units. Visibility degradation is 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 (b_{ext}) and visual range. The light extinction coefficient is 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, and soil (Sisler, 1996).

Visual range is a measure of visibility that is inversely related to the extinction coefficient. Visual range can be defined as the maximum distance at which one can identify a black object against the horizon sky. Visual range (in units of kilometers) can be calculated from b_{ext} using the formula: Visual Range (km) = $3912/b_{ext}$ (b_{ext} units are inverse megameters [Mm^{-1}])

The future year visibility impairment was calculated using a methodology which applies modeling results in a relative sense similar to the Speciated Modeled Attainment Test (SMAT).

In calculating visibility impairment, the extinction coefficient is made up of individual component species (sulfate, nitrate, organics, etc). The predicted change in visibility is calculated as the percent change in the extinction coefficient for each of the PM species (on a daily average basis). The individual daily species extinction coefficients are summed to get a daily total extinction value. The daily extinction coefficients are converted

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[G] There are 81 IMPROVE sites with complete data for 2001. Many of these sites collect data that is "representative" of other nearby unmonitored mandatory class I federal areas. There are a total of 116 mandatory class I federal areas that are represented by the 81 sites. The matching of sites to monitors is taken from "Guidance for Tracking Progress Under the Regional Haze Rule".

to visual range and then averaged across all days. In this way, we can calculate annual average extinction and visual range at each IMPROVE site. Subtracting the annual average control case visual range from the base case visual range gives a projected improvement in visual range (in km) at each mandatory class I federal area. This serves as the visibility input for the benefits analysis (See Chapter 6).

For visibility calculations, we are continuing to use the IMPROVE program species definitions and visibility formulas which are recommended in the draft modeling guidance. Each IMPROVE site has measurements of $PM_{2.5}$ species and therefore we do not need to estimate the species fractions in the same way that we did for FRM sites (using interpolation techniques and other assumptions concerning volatilization of species).

2.1.6.2 Other PM Related Welfare Effects

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominately from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). Reflecting this fact, the PM AQCD concludes that regardless of size fractions, particles containing nitrates and sulfates have the greatest potential for widespread environmental significance, while effects are also related to other chemical constituents found in ambient PM, such as trace metals and organics. (The Staff Paper notes that some of these other components are regulated under separate statutory authorities, e.g., section 112 of the CAA.) The following characterizations of the nature of these welfare effects are based on the information contained in the PM AQCD and Staff Paper.

2.1.6.2.1 *Effects on Vegetation and Ecosystems*

Potentially adverse PM-related effects on vegetation and ecosystems are principally associated with particulate nitrate and sulfate deposition. In characterizing such effects, it is important to recognize that nitrogen and sulfur are necessary and beneficial nutrients for most organisms that make up ecosystems, with optimal amounts of these nutrients varying across organisms, populations, communities, ecosystems and time scales. Therefore, it is impossible to generalize to all species in all circumstances as to the amount at which inputs of these nutrients or acidifying compounds become stressors. The Staff Paper recognizes the public welfare benefits from the use of nitrogen (N) and sulfur (S) nutrients in fertilizers in managed agricultural and commercial forest settings.

2.1.6.2.1.1 Vegetation Effects

At current ambient levels, risks to vegetation from short-term exposures to dry deposited particulate nitrate or sulfate are low. However, when found in acid or acidifying deposition, such particles do have the potential to cause direct leaf injury. Specifically, the responses of forest trees to acid precipitation (rain, snow) include accelerated weathering of leaf cuticular surfaces, increased permeability of leaf surfaces to toxic materials, water, and disease agents; increased leaching of nutrients from foliage; and altered reproductive processes—all which serve to weaken trees so that they are more susceptible to other stresses (e.g., extreme weather, pests, pathogens). Acid deposition with levels of acidity associated with the leaf effects described above are currently found in some locations in the eastern US (EPA 2003). Even higher concentrations of acidity can be present in occult depositions (e.g., fog, mist or clouds) which more frequently impacts higher elevations. Thus, the risks of leaf injury occurring from acid deposition in some areas of the eastern U.S. is high. However, based on currently available information, the contribution of particulate sulfates and nitrates to the total acidity found at these locations is not clear.

2.1.6.2.1.2 Ecosystem Effects

The nitrogen and sulfur containing components of PM have been associated with a broad spectrum of ecosystems impacts that result from either the nutrients or acidifying characteristics of the deposited compounds.

Reactive nitrogen is the form of nitrogen that is available to support the growth of plants and microorganisms. Since the mid-1960's reactive nitrogen creation through natural processes has been overtaken by reactive nitrogen creation as a result of human processes, and is now accumulating in the environment on the local, regional and global scale. Some reactive nitrogen emission are transformed into ambient PM and deposited onto sensitive ecosystems. Some of the most significant detrimental effects associated with excess reactive nitrogen deposition are those associated with a syndrome known as "nitrogen saturations.: These effects include; (1) Decreased productivity, increased mortality, and/or shifts in plant community composition, often leading to decreased biodiversity in many natural habitats wherever atmospheric reactive nitrogen deposition increases significantly and critical thresholds are exceeded; (2) leaching of excess nitrate and associated base cations from soils into streams, lakes, and rivers, and mobilization of soil aluminum; and (3) alternation of ecosystem processes such as nutrient and energy cycles through changes in the functioning and species composition of beneficial soil organisms (Galloway and Cowling, 2002). Thus, through its effects on habitat suitability, genetic diversity, community dynamics and composition, nutrient status, energy and nutrient cycling, and frequency and intensity of natural disturbance regimes (fire), exceed reactive nitrogen deposition is have profound and adverse impact on essential ecological attributes associated with terrestrial ecosystems. In the US numerous forests now show severe symptoms of nitrogen saturation. For other forested locations, ongoing expansion in nearby urban areas will increase the potential for nitrogen saturation unless there are improved emissions controls.

Excess nutrient inputs into aquatic ecosystems (i.e. streams, rivers, lakes, estuaries or oceans) either form direct atmospheric deposition, surface runoff, or leaching from nitrogen saturated soils into ground or surface waters can contribute to conditions of severe water oxygen depletion; eutrophication and algae blooms; altered fish distributions, catches, and physiological states; loss of biodiversity; habitat degradation; and increases in the incidence of disease.

In the U.S., forests that are now showing severe symptoms of nitrogen saturation include: the northern hardwoods and mixed conifer forests in the Adirondack and Catskill Mountains of New York; the red spruce forests at Whitetop Mountain, Virginia, and Great Smoky Mountains National Park, North Carolina; mixed hardwood watersheds at Fernow Experimental Forest in West Virginia; American beech forests in Great Smoky Mountains

National Park, Tennessee; mixed conifer forests and chaparral watersheds in southern California and the southwestern Sierra Nevada in Central California; the alpine tundra/subalpine conifer forests of the Colorado Front Range; and red alder forests in the Cascade Mountains in Washington.

2.1.6.2.1.2.1 Eutrophication, Nitrification, and Fertilization

In recent decades, human activities have greatly accelerated nutrient impacts, such as nitrogen deposition in both aquatic and terrestrial systems. Nitrogen deposition in aquatic systems can cause excessive growth of algae and lead to degraded water quality and associated impairment of fresh water and estuarine resources for human uses. [61] Nitrogen deposition on terrestrial systems can cause fertilization and lead to ecosystem stress and species shift.

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 adversely affect fish and shellfish populations.

Deposition of nitrogen contributes to elevated nitrogen levels in waterbodies. The NO_x reductions from today's promulgated standards will help 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.

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. [625]

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. [63] A review of peer reviewed literature in 1995 on the subject of air deposition suggests a typical contribution of 20 percent or higher.[64] 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.[65] The National Exposure Research Laboratory, U.S. EPA, estimated based on prior studies that 20 to 35 percent of the nitrogen loading to the Chesapeake Bay is attributable to atmospheric deposition.[66] The mobile source portion of atmospheric NO_x contribution to the Chesapeake Bay was modeled at about 30 percent of total air deposition.[10]

In U.S. terrestrial systems, the nutrient whose supply most often sets the limit of possible plant based productivity at a given site is nitrogen. By increasing available nitrogen, overall ecosystem productivity may be expected to increase for a time, and then decline as nitrogen saturation is reached. However, because not all vegetation, organisms, or ecosystems react in the same manner to increased nitrogen fertilization, those plants or organisms that are predisposed to capitalize on any increases in nitrogen availability gain an advantage over those that are not as responsive to added nutrients, leading to a change in plant community composition and diversity. Changes to plant community composition and structure within an ecosystem are of concern because plants in large part determine the food supply and habitat types available for use by other organisms. Further, in terrestrial systems, plants serve as the integrators between above-ground and below-ground environments and influence nutrient, energy and water cycles. Because of these linkages, chronic excess nutrient nitrogen additions can lead to complex, dramatic, and severe ecosystem level responses such as changes in habitat suitability, genetic diversity, community dynamics and composition, nutrient status, energy and nutrient cycling, and frequency and intensity of natural disturbance regimes such as fire.

These types of effects have been observed both experimentally and in the field. For example, experimental additions of nitrogen to a Minnesota grassland dominated by native warm-season grasses produced a shift to low-diversity mixtures dominated by coolseason grasses over a 12 year period at all but the lowest rate of nitrogen addition.[67] Similarly, the coastal sage scrub (CSS) community in California has been declining in land area and in drought deciduous shrub density over the past 60 years, and is being replaced in many areas by the more nitrogen responsive Mediterranean annual grasses. Some 25 plant species are already extinct in California, most of them annual and perennial forbs that occurred in sites now experiencing conversion to annual grassland. As CSS converts more extensively to annual grassland dominated by invasive species, loss of additional rare species may be inevitable. Though invasive species are often identified as the main threat to rare species, it is more likely that invasive species combine with other factors, such as excess N deposition, to promote increased productivity of invasive species and resulting species shifts.

Deposition of nitrogen from the engines covered in this proposal contributes to elevated nitrogen levels in bodies of water and on land. The NO_x reductions proposed in this action will reduce the airborne nitrogen deposition that contributes to eutrophication of watersheds and nitrogen saturation on land.

2.1.6.2.1.2.2 Atmospheric Deposition

Wet and dry deposition of ambient particulate matter delivers a complex mixture of metals (e.g., mercury, zinc, lead, nickel, aluminum, and cadmium), organic compounds (e.g., POM, dioxins, and furans) and inorganic compounds (e.g., nitrate, sulfate) to terrestrial and aquatic ecosystems. The chemical form of the compounds deposited is impacted by a variety of factors including ambient conditions (e.g., temperature, humidity, oxidant levels) and the sources of the material. Chemical and physical transformations of the particulate compounds occur in the atmosphere as well as the media onto which they deposit. These transformations in turn influence the fate, bioavailability and potential toxicity of these compounds. Atmospheric deposition has been identified as a key component of the environmental and human health hazard posed by several pollutants including mercury, dioxin and PCBs.[68]

Adverse impacts on water quality can occur when atmospheric contaminants deposit to the water surface or when material deposited on the land enters a water body through runoff. Potential impacts of atmospheric deposition to water bodies include those related to both nutrient and toxic inputs. Adverse effects to human health and welfare can occur from the addition of excess particulate nitrate nutrient enrichment which contribute to toxic algae blooms and zones of depleted oxygen that can lead to fish kills, frequently in coastal waters. Particles contaminated with heavy metals or other toxins may lead to the ingestion of contaminated fish, ingestion of contaminated water, damage to the marine ecology, and limited recreational uses. Several studies have been conducted in U.S. coastal waters and in the Great Lakes Region in which the role of ambient PM deposition and runoff is investigated.[69,70,71,72,73]

Adverse impacts on soil chemistry and plant life have been observed for areas heavily impacted by atmospheric deposition of nutrients, metals and acid species, resulting in species shifts, loss of biodiversity, forest decline and damage to forest productivity. Potential impacts also include adverse effects to human health through ingestion of contaminated vegetation or livestock (as in the case for dioxin deposition), reduction in crop yield, and limited use of land due to contamination.

In the following subsections, atmospheric deposition of heavy metals and particulate organic material is discussed.

2.1.6.2.1.2.2.1 Heavy Metals

Heavy metals, including cadmium, copper, lead, chromium, mercury, nickel and zinc, have the greatest potential for influencing forest growth (PM AQCD, p. 4-87).[74] Investigation of trace metals near roadways and industrial facilities indicate that a substantial burden of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel have been documented to cause direct toxicity to vegetation under field conditions (PM AQCD, p. 4-75). Little research has been conducted on the effects associated with mixtures of contaminants found in ambient PM. While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment.

Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline (PM AQCD, p. 4-76).[75] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops (PM AQCD, p. 4-75). As the fallen leaves decompose, the heavy metals are transferred into the soil.[76,77]

The environmental sources and cycling of mercury are currently of particular concern due to the bioaccumulation and biomagnification of this metal in aquatic ecosystems and the potent toxic nature of mercury in the forms in which is it ingested by people and other animals. Mercury is unusual compared with other metals in that it largely partitions into the gas phase (in elemental form), and therefore has a longer residence time in the atmosphere than a metal found predominantly in the particle phase. This property enables mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.[78,79] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[80] Overall, the National Science and Technology Council (NSTC, 1999) identifies atmospheric deposition as the primary source of mercury to aquatic systems. Forty-four states have issued health advisories for the consumption of fish contaminated by mercury; however, most of these advisories are issued in areas without a mercury point source.

Elevated levels of zinc and lead have been identified in streambed sediments, and these elevated levels have been correlated with population density and motor vehicle use.[81,82] Zinc and nickel have also been identified in urban water and soils. In addition, platinum, palladium, and rhodium, metals found in the catalysts of modern motor vehicles, have been measured at elevated levels along roadsides.[83] Plant uptake of platinum has been observed at these locations.

2.1.6.2.1.2.2.2 Polycyclic Organic Matter

Polycyclic organic matter (POM) is a byproduct of incomplete combustion and consists of organic compounds with more than one benzene ring and a boiling point greater than or equal to 100 degrees centigrade.[84] Polycyclic aromatic hydrocarbons (PAHs) are a class of POM that contain compounds which are known or suspected carcinogens.

Major sources of PAHs include mobile sources. PAHs in the environment may be present as a gas or adsorbed onto airborne particulate matter. Since the majority of PAHs are adsorbed onto particles less than 1.0 µm in diameter, long range transport is possible. However, studies have shown that PAH compounds adsorbed onto diesel exhaust particulate and exposed to ozone have half lives of 0.5 to 1.0 hours.[85]

Since PAHs are insoluble, the compounds generally are particle reactive and accumulate in sediments. Atmospheric deposition of particles is believed to be the major source of PAHs to the sediments of Lake Michigan.[86,87] Analyses of PAH deposition to Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[88,89] Sediment concentrations of PAHs are high enough in some segments of Tampa Bay to pose an environmental health threat. EPA funded a study to better characterize the sources and loading rates for PAHs into Tampa Bay.[90] PAHs that enter a water body through gas exchange likely partition into organic rich particles and be biologically recycled, while dry deposition of aerosols containing PAHs tends to be more resistant to biological recycling.[91] Thus, dry deposition is likely the main pathway for PAH concentrations in sediments while gas/water exchange at the surface may lead to PAH distribution into the food web, leading to increased health risk concerns.

Trends in PAH deposition levels are difficult to discern because of highly variable ambient air concentrations, lack of consistency in monitoring methods, and the significant influence of local sources on deposition levels.[92] Van Metre et al. (2000) noted PAH concentrations in urban reservoir sediments have increased by 200-300% over the last forty years and correlates with increases in automobile use.[93]

Cousins et al. (1999) estimates that greater than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[94] An analysis of polycyclic aromatic hydrocarbon (PAH) concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater.

2.1.6.2.1.2.2.3 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.[95] 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.

2.2 Ozone

In this section we review the health and welfare effects of ozone. We also describe the air quality monitoring and modeling data which indicate that people in many areas across the country continue to be exposed to high levels of ambient ozone and will continue to be into the future. Emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) from locomotive and marine diesel engines subject to this proposed rule have been shown to contribute to these ozone concentrations. Information on air quality was gathered from a variety of sources, including monitored ozone concentrations, air quality modeling forecasts conducted for this rulemaking, and other state and local air quality information.

The proposed emission reductions from this rule would assist 8-hour ozone nonattainment and maintenance areas in reaching the standard by each area’s respective attainment date, and maintaining the 8-hour ozone standard in the future. The emission reductions will also help continue to lower ambient ozone levels and resulting health impacts.

2.2.1 Science of Ozone Formation

Ground-level ozone pollution is formed by the reaction of VOCs and nitrogen oxides (NO_x) 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 such as highway and nonroad vehicles, power plants, chemical plants, refineries, makers of consumer and commercial products, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex.[96] Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which 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 result in more ozone than typically would occur on a single high-temperature day. 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 NO_x emissions.

The highest levels of ozone are produced when both VOC and NO_x emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_x enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_x. Under these conditions NO_x reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NO_x-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 NO_x -limited.

When NO_x levels are relatively high and VOC levels relatively low, NO_x 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 NO_x reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO_x reductions are not expected to increase ozone levels if the NO_x reductions are sufficiently large.

Rural areas are usually NO_x-limited, due to the relatively large amounts of biogenic VOC emissions in many rural areas. Urban areas can be either VOC- or NO_x -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 NO_x, VOC, and ozone, all of which change with time and location.

The current ozone National Ambient Air Quality Standards (NAAQS) has an 8-hour averaging time.[H] The 8-hour ozone NAAQS, established by EPA in 1997, is based on well-documented science demonstrating that more people were experiencing adverse health effects at lower levels of exertion, over longer periods, and at lower ozone concentrations than addressed by the previous one-hour ozone NAAQS. The current ozone NAAQS

[H] EPA's review of the ozone NAAQS is underway and a proposal is scheduled for May 2007 with a final rule scheduled for February 2008.

addresses 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. The 8-hour ozone NAAQS is met at an ambient air quality monitoring site when the average of the annual fourth-highest daily maximum 8-hour average ozone concentration over three years is less than or equal to 0.084 ppm.

2.2.2 Health Effects of Ozone

Exposure to ambient ozone contributes to a wide range of adverse health effects[I]. These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[97,98] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, inflammation of the lungs and a variety of other respiratory effects and cardiovascular effects. People who are more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. There is also suggestive evidence that certain people may have greater genetic susceptibility. Those with greater exposures to ozone, for instance du to time spent outdoors (e.g. outdoor workers), are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 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.[99, 100, 101, 102, 103, 104] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[105, 106, 107, 108, 109] Repeated exposure to sufficient concentrations of ozone can also 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.[110, 111, 112, 113]

Children and adults who are outdoors and active during the summer months, such as construction workers and other outdoor workers, are among those most at risk of elevated ozone exposures.[114] Children and outdoor workers tend to have higher ozone exposure because they typically are active outside, working, playing and exercising, during times of day and seasons (e.g. the summer) when ozone levels are highest.[115] For example, summer camp studies in the Eastern United States and Southeastern Canada have reported significant reductions in lung function in children who are active outdoors.[116, 117, 118, 119, 120, 121, 122, 123]

[I] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentration but also by the individuals breathing route and rate.

Further, children are more at risk of experiencing health effects from ozone exposure than adults 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.[124, 125, 126, 127]

EPA typically quantifies ozone-related health impacts in its regulatory impact analyses (RIAs) when possible. In the analysis of past air quality regulations, ozone-related benefits have included morbidity endpoints and welfare effects such as damage to commercial crops. EPA has not recently included a separate and additive mortality effect for ozone, independent of the effect associated with fine particulate matter. For a number of reasons, including 1) advice from the Science Advisory Board (SAB) Health and Ecological Effects Subcommittee (HEES) that EPA consider the plausibility and viability of including an estimate of premature mortality associated with short-term ozone exposure in its benefits analyses and 2) conclusions regarding the scientific support for such relationships in EPA's 2006 Air Quality Criteria for Ozone and Related Photochemical Oxidants (the CD), EPA is in the process of determining how to appropriately characterize ozone-related mortality benefits within the context of benefits analyses for air quality regulations. As part of this process, we are seeking advice from the National Academy of Sciences (NAS) regarding how the ozone-mortality literature should be used to quantify the reduction in premature mortality due to diminished exposure to ozone, the amount of life expectancy to be added and the monetary value of this increased life expectancy in the context of health benefits analyses associated with regulatory assessments.

Since the NAS effort is not expected to conclude until 2008, the agency is currently deliberating how best to characterize ozone-related mortality benefits in its rulemaking analyses in the interim. For the analysis of the proposed locomotive and marine standards, we do not quantify an ozone mortality benefit. So that we do not provide an incomplete picture of all of the benefits associated with reductions in emissions of ozone precursors, we have chosen not to include an estimate of total ozone benefits in the proposed RIA. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards. For more information regarding the quantified benefits included in this analysis, please refer to Chapter 6.

2.2.3 Current 8-Hour Ozone Levels

The proposed locomotive and marine engine emission reductions will assist 8-hour ozone nonattainment areas in reaching the standard by each area's respective attainment date and assist in maintaining the 8-hour ozone standard in the future. In this section and the next section we present information on current and model-projected future 8-hour ozone levels.

A nonattainment area is defined in the CAA as an area that is violating a NAAQS or is contributing to a nearby area that is violating the NAAQS. EPA designated nonattainment areas for the 8-hour ozone NAAQS in June 2004. The final rule on Air Quality Designations and Classifications for the 8-hour Ozone NAAQS (69 FR 23858, April 30, 2004) lays out the factors that EPA considered in making the 8-hour ozone nonattainment designations, including 2001-2003 measured data, air quality in adjacent areas, and other factors.[J]

As of October 2006 there are approximately 157 million people living in 116 areas designated as not in attainment with the 8-hour ozone NAAQS. There are 461 full or partial counties that make up the 8-hour ozone nonattainment areas. These numbers do not include the people living in areas where there is a future risk of failing to maintain or achieve the 8-hour ozone NAAQS. Figure 2-1 illustrates the widespread nature of these current problems. Shown in this figure are counties designated as nonattainment for the 8-hour ozone NAAQS, $PM_{2.5}$ nonattainment counties, and mandatory class I federal areas. The current 8-hour ozone nonattainment areas, nonattainment counties, and populations are listed in Appendix 2C to this draft RIA.

Counties designated as 8-hour ozone nonattainment were classified, on the basis of their one-hour ozone design value, as Subpart 1 or Subpart 2 (69 FR 23951, April 30, 2004). Areas classified as Subpart 2 were then further classified, on the basis of their 8-hour ozone design value, as marginal, moderate, serious, severe or extreme. The maximum attainment date assigned to an ozone nonattainment area is based on the area's classification.

States with 8-hour ozone nonattainment areas will be required to take action to bring those areas into compliance in the future. Based on the final rule designating and classifying 8-hour ozone nonattainment areas (69 FR 23951, April 30, 2004), most 8-hour ozone nonattainment areas will be required to attain the 8-hour ozone NAAQS in the 2007 to 2013 time frame and then be required to maintain the 8-hour ozone NAAQS thereafter.[K] We expect many of the 8-hour ozone nonattainment areas will need to adopt additional emission reduction programs. The expected NO_x and VOC reductions from the standards proposed in this action would be useful to states as they seek to either attain or maintain the 8-hour ozone NAAQS.

Further insight into the need for reductions from this rule can be gained by evaluating counties at various levels above the level of the 8-hour ozone NAAQS. As shown in Table 2-4 below, of the 158 million people living in counties with 2001-2003 design value

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[J] 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 three 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. 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 or 85 parts per billion (ppb). 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. However, readers should note that ozone design values generally represent air quality across a broad area and that absence of a design value does not imply that the county is in compliance with the ozone NAAQS**.** Therefore, our analysis may underestimate the number of counties with design values above the level of NAAQS.

[K] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area will have to attain before June 15, 2021.

measurements above the 8-hour ozone NAAQS, almost 90 million live in counties with 2001-2003 8-hour ozone design values above 95 ppb.

Table 2-4 Population Living in Counties with 2001-2003 8-hour Ozone Design Values Shown

2001-2003 8-hour Ozone Design Value (ppb)	Number of Counties Within The Concentration Range	2000 Population Living in Counties Within The Concentration Range (Millions, 2000 Census Data)
>95	25	89.7
>90 <=95	47	40.0
>85 <= 90	54	29.6

EPA's review of the ozone NAAQS is currently underway and a proposal is scheduled for June 2007 with a final rule scheduled for March 2008. If the ozone NAAQS is revised then new nonattainment areas could be designated. While EPA is not relying on it for purposes of justifying this proposal, the emission reductions from this proposed rulemaking would also be helpful to states if there is an ozone NAAQS revision.

2.2.4 Projected 8-Hour Ozone Levels

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the Clean Air Interstate Rule (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel rule (69 FR 38957, June 29, 2004), and the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001). As a result of these programs, the number of areas that fail to meet the 8-hour ozone NAAQS in the future is expected to decrease.

The base case air quality modeling completed for this proposed rule predicts that without additional local, regional or national controls there will continue to be a need for reductions in 8-hour ozone concentrations in some areas in the future. The determination that an area is at risk of exceeding the 8-hour ozone standard in the future was made for all areas with current design values greater than or equal to 85 ppb (or within a 10 percent margin) and with modeling evidence that concentrations at and above this level will persist into the future. Those interested in greater detail should review the air quality modeling TSD.

With reductions from programs already in place (but excluding the emission reductions from this rule), the number of counties with projected 8-hour ozone design values at or above 85 ppb in 2020 is expected to be 31 counties where 35 million people are projected to live. In addition, in 2020, 89 counties where 60 million people are projected to live, will be within 10 percent of violating the 8-hour ozone NAAQS. Table 2- 5 below provides the full list of counties in 2020 projected to have design values at or above 85 ppb as well as the 89 counties within 10 percent of violating the NAAQS in 2020. By 2030 27 current ozone nonattainment counties would still remain impacting 37 million people. Even in 2030, 75 million people, living in 108 counties would continue to be within 10 percent of the current 8-hour ozone standard.

Clearly the almost 300,000 tons of annual NO_x reductions in 2020 and the more than 7650,000 NO_x tons reduced in 2030 would be very important to these areas as they struggle to attain the 8-hour ozone standard or continue to maintain the standards. Table 2-5 below shows the current 8-hour ozone nonattainment areas which are projected to be in nonattainment in 2020 and 2030 as well as those current nonattainment areas, which will be in attainment but within 10 percent of not meeting the standard. The table also presents ozone design values and populations in 2020 and 2030.

Table 2-5 Counties with 2020 and 2030 projected Annual 8-hour Ozone Design Values in Violation or within 10 percent of the Annual Ozone Standard in the Base and Control Cases.

State	County	2001-2003 Average Ozone DV (ppb)	2020		2030		2020 population
			base	control	base	control	
AZ	Maricopa	85.0	X	X	X	X	4,609,780
CA	Amador	88.0	X	X	X	X	52,471
CA	Calaveras	92.3	X	X	X		58,261
CA	El Dorado	105.7	X	X	X	X	236,310
CA	Fresno	111.3	V	V	V	X	1,066,878
CA	Imperial	87.0	V	V	V	V	161,555
CA	Kern	112.0	X	X	X	X	876,131
CA	Kings	97.3	V	V	V	V	173,390
CA	Los Angeles	110.0	V	V	X	X	10,376,013
CA	Madera	90.7	V	V	V	V	173,940
CA	Mariposa	88.3	X	X	X	X	22,272
CA	Merced	101.3	V	V	X	X	277,863
CA	Nevada	97.7	V	V	V	V	131,831
CA	Orange	82.7	X	X	X	X	3,900,599
CA	Placer	100.3	X	X	X		451,620
CA	Riverside	108.7	V	V	X	X	2,252,510
CA	Sacramento	99.7	V	V	V	V	1,640,590
CA	San Bernardino	129.3	X	X	X	X	2,424,764
CA	San Diego	94.0	V	V	V	V	3,863,460
CA	Stanislaus	94.0	X	X	X	X	607,766
CA	Tehama	84.3	X	X			64,298
CA	Tulare	105.3	X	X			477,296
CA	Tuolumne	91.5	V	V	V	V	70,570
CA	Ventura	97.7	V	X	X	X	1,023,136
CO	Douglas	82.5	V	V	V	V	303,846
CO	Jefferson	83.7	X	X	X	X	655,782
CT	Fairfield	98.7	X	X	X	X	962,824
CT	Hartford	89.3	V	V	V	V	942,284
CT	Middlesex	98.0	X	X	X	X	177,500

CT	New Haven	99.0	V	V	V	V	898,415
CT	New London	90.7	V	V	V	V	280,729
CT	Tolland	93.0	X	X	X	X	152,653
DC	Washington	94.3	X	X	X	X	554,330
DE	Kent	91.3	X	X	X	X	153,635
DE	New Castle	95.3	X		X		584,627
DE	Sussex	93.3	X	X	X	X	202,387
GA	De Kalb	95.3	X	X	X		801,817
GA	Fulton	99.0	X	X	X		929,278
IL	Cook	87.7	X	X	X	X	5,669,479
IN	Hamilton	93.3	X	X	X	X	279,537
IN	Lake	90.7	X	X	X		509,293
IN	Marion	90.0	X	V	X	X	935,610
IN	Porter	89.0	X				188,604
IN	Shelby	93.5	X				50,387
KY	Campbell	91.7	X	X			95,622
LA	East Baton Rou	87.3	X	X	X		522,399
LA	Iberville	86.7	X	X	X		33,130
MD	Anne Arundel	101.0	X		X		596,924
MD	Baltimore	93.0	X	X	V	X	855,464
MD	Cecil	102.7	X	X	X	X	109,425
MD	Harford	103.7	V	V	V	V	317,847
MD	Kent	99.0	V	V	V	V	21,407
MD	Montgomery	88.7	X	X	X	X	1,060,716
MD	Prince Georges	95.0	X	X	X	X	944,987
MA	Barnstable	94.7	X	X	X	X	283,735
MA	Bristol	92.7	X	X	X	X	605,591
MI	Allegan	92.0	X	X	X	X	141,851
MI	Macomb	91.0	X	X			894,095
MI	Muskegon	92.0	X	X	X	X	183,444
MI	Oakland	87.0	X	X	X	X	1,443,380
MI	Wayne	88.0	X	X	X	X	1,908,196
MO	St Louis	89.3	X	X	X	X	1,057,171
MO	St Louis City	87.0	X	X	X	X	303,712
NJ	Bergen	92.5	X	X	X		944,507
NJ	Camden	102.3	X	X	X	X	547,817
NJ	Cumberland	96.7	V	V	V	V	161,512
NJ	Gloucester	100.3	X	X	X	X	304,105
NJ	Hudson	88.0	V	V	V	V	694,357
NJ	Hunterdon	97.3	X	X	X	X	160,989
NJ	Mercer	102.3	X	X	X	X	392,236
NJ	Middlesex	100.7	V	V	V	V	934,654
NJ	Monmouth	95.7	V	V	V	V	741,640
NJ	Morris	97.7	V	X	V	X	548,694
NJ	Ocean	109.0	X	X	X	X	644,323
NY	Erie	96.0	V	V	V	V	959,145
NY	Jefferson	91.7	X	X	X	X	119,264
NY	Niagara	91.0	X	X	X		220,989
NY	Putnam	91.3	X	X	X	X	124,395
NY	Richmond	96.0	X	X	X	X	561,360
NY	Suffolk	98.5	X	X	X	X	1,598,742
NY	Westchester	92.0	V	V	V	V	1,027,798

OH	Ashtabula	94.0	X	X	X	X	108,355
OH	Geauga	98.3	X	X	X	X	114,438
OH	Lake	92.7	X	X	X	X	250,353
PA	Allegheny	93.0	X	X	X	X	1,242,587
PA	Beaver	90.7	X	X	X	X	186,566
PA	Bucks	103.0	X	X	X	X	711,275
PA	Chester	96.5	V	V	V	V	528,797
PA	Delaware	93.7	X	X	X	X	548,283
PA	Lancaster	94.0	X	X	X	X	568,258
PA	Lehigh	93.3	X	X	X		351,875
PA	Montgomery	96.3	X	X	X		805,003
PA	Northampton	93.0	X	X	X	X	301,041
PA	Philadelphia	97.5	X	X	X		1,394,176
RI	Kent	95.3	V	V	V	V	183,833
RI	Providence	90.3	X	X	X	X	648,008
RI	Washington	93.3	X	X	X	X	156,286
TX	Brazoria	91.0	X	X	X	X	322,385
TX	Dallas	91.0	X	X	X	X	2,828,339
TX	Denton	99.0	X	X	X	X	715,168
TX	Galveston	92.0	X	X	X		318,966
TX	Gregg	88.3	X	X	X	X	132,922
TX	Harris	105.0	X	X	X	X	4,588,812
TX	Jefferson	90.5	V	V	V	V	272,075
TX	Tarrant	98.3	X	X	X	X	2,137,957
VA	Alexandria Cit	90.0	X	X	X	X	132,893
VA	Arlington	95.7	X	X	X	X	208,368
VA	Charles City	89.3	V	V	V	V	8,086
VA	Fairfax	96.3	X	X	X		1,281,265
VA	Hampton City	88.7	X	X	X	X	161,913
VA	Hanover	94.0	X	X	X	X	109,984
VA	Suffolk City	87.3	X	X	X	X	72,313
WI	Door	92.7	X	X		X	34,106
WI	Kenosha	98.7	X	X	X		184,825
WI	Kewaunee	90.0	V	V	V	V	21,040
WI	Manitowoc	90.0	X	X	X		85,187
WI	Milwaukee	91.3	X	X	X	X	927,845
WI	Ozaukee	95.3	X	X	X	X	110,294
WI	Racine	91.7	X	X	X	X	212,351
WI	Sheboygan	98.0	X	X	X	X	128,777

2.2.4.1 Ozone Modeling Results with proposed controls

This section summarizes the results of our modeling of ozone air quality impacts in the future due to the reductions in locomotive and marine diesel emissions proposed in this action. Specifically, we compare baseline scenarios to scenarios with the proposed controls. Our modeling indicates that the reductions from this proposed rule will contribute to reducing ambient ozone concentrations and potential exposures in future years.

According to air quality modeling performed for this rulemaking, the proposed locomotive and marine diesel engines standards are expected to provide nationwide improvements in ozone levels for the vast majority of areas. Specifically, this proposed rule would result in ozone benefits for all but two U.S. ozone nonattainment areas in both their 2020 and 2030 ozone design values. There are two areas with small (i.e., less than 1 ppb) increases in their annual 8- hour ozone design values due to the NO_x disbenefits which occurs in some VOC-limited ozone nonattainment areas. Briefly NO_x reductions can at certain times and in some areas cause ozone levels to increase slightly. Section 2.2.4.1.1 provides additional detail about NO_x disbenefits.

Despite of the localized areas that experience small increases, the overall effect of this proposed rule is positive with 454 (of 473) counties experiencing at least a 0.1 ppb decrease in both their 2020 and 2030 ozone design values. On a population-weighted basis, the average modeled future-year 8-hour ozone design values would decrease by 0.29 ppb in 2020 and 0.80 ppb in 2030. Within projected ozone nonattainment areas in 2030, the average decrease would be somewhat higher: -0.30 ppb in 2020 and - 0.88 ppb in 2030 while the *maximum* decrease for future-year design values would be -1.10 ppb in 2020 and -2.90 ppb in 2030.

Table 2-6 shows the average change in future year eight-hour ozone design values. Average changes are shown 1) for all counties with 2020 baseline design values, 2) for counties with baseline design values that exceeded the standard in 2001-2003 (“violating” counties), and 3) for counties that did not exceed the standard, but were within 10 percent of it in 2001-2003. 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 demonstrates a broad improvement in ozone air quality. The average across violating counties shows that the proposed rule will help bring these counties into attainment. Since some of the VOC and NO_x emission reductions expected from this proposed rule will go into effect during the period when areas will need to attain the 8-hour ozone NAAQS, the projected reductions in emissions are expected to assist States and local agencies in their effort to attain and maintain the 8-hour ozone standard. The average over counties within ten percent of the standard shows that the proposed 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, indicating in four different ways the overall improvement in ozone air quality.

Table 2-6 Average change in projected future year 8-hour ozone design value

Average[a]	Number of US Counties	Change in 2020 design value[b] (ppb)	Change in 2030 design value[b] (ppb)
All	473	0.32	0.86
All, population-weighted	473	0.29	0.80
Violating counties[c]	277	0.33	0.88
Violating counties[c], population-weighted	277	0.29	0.87

Counties within 10 percent of the standard[d]	146	0.35	0.94
Counties within 10 percent of the standard[d], population-weighted	146	0.32	1.02

a) averages are over counties with 2020 modeled design values

b) assuming the nominal modeled control scenario

c) counties whose 2001 baseline design values exceeded the 8-hour ozone standard (>= 85 ppb)

d) counties whose 2001 baseline values were less than but within 10 percent of the 8-hour ozone standard.

The impact of the proposed reductions has also been analyzed with respect to those areas that have the highest projected design values. We project that there will be 27 US counties with design values at or above 85 ppb in 2030. After implementation of this proposed action, we project that 3 of these 27 counties will attain the standard. Further, 17 of the 27 counties will be at least 10 percent closer to a design value of less than 85 ppb, and on average all 27 counties will be 29 percent closer to a design value of less than 85 ppb.

The geographic impact of these emissions reductions in 2030 on annual ozone design values in counties across the US, can be seen in Figure 2-9.

Figure 2-9 Impact of Proposed Locomotive/Marine controls on annual Ozone Design Values (DV) in 2030

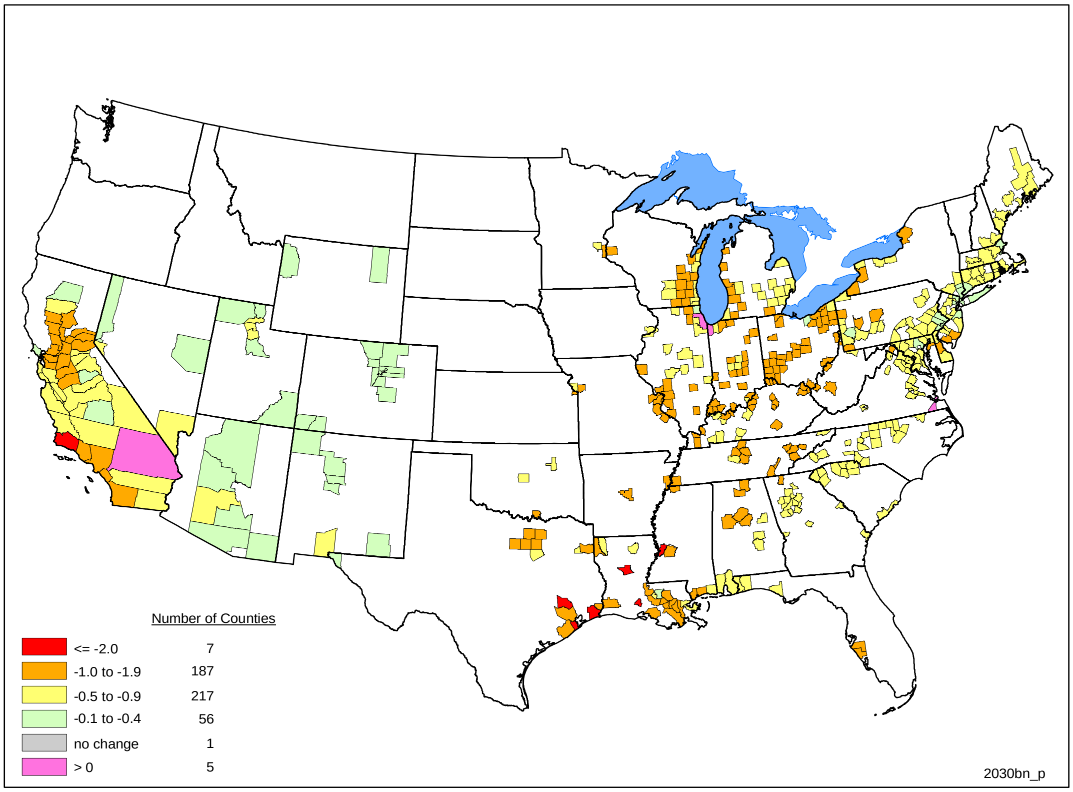

Figure 2.9 shows those US counties in 2030 which are projected to experience a change in their ozone design values as a result of this proposed rule. The most significant decreases, equal or greater than -2.0 ppb, would occur in 7 counties across the US including: Grant (-2.1ppb) and Lafayette (-2.0 ppb) Counties in Louisiana; Montgomery (-2.0 ppb), Galveston (-2.0ppb), and Jefferson (-2.0 ppb) Counties in Texas; Warren County (-2.9 ppb) in Mississippi; and Santa Barbara County (-2.7 ppb) in California. One hundred eighty-seven (187) counties would see annual ozone design value reductions from -1.0 to -1.9 ppb while an estimated 217 additional counties would see annual design value reductions from -0.5 to -0.9 ppb. Note that 5 counties including: Suffolk (+1.5 ppb) and Hampton (+ 0.8 ppb) Counties in Virginia; Cook County (+ 0.7 ppb) in Illinois; Lake County (+ 0.2 ppb) in Indiana; and San Bernardino County (+ 0.1 ppb) in California are projected to experience increased ozone design values because of the NOx disbenefit that occurs under certain conditions.

It should be noted that the emission control scenarios used in the air quality and benefits modeling are slightly different than the emission control program being proposed. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Chapter 3 of this RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final proposed regulatory scenario. These refinements to the proposed program would not significantly change the results summarized here or our conclusions drawn from this analysis.

2.2.4.1.1 *Potentially Counterproductive Impacts on Ozone Concentrations from NO_x Emissions Reductions*

While the proposed rule would reduce ozone levels generally and provide significant national ozone-related health benefits, this is not always the case at the local level. Due to the complex photochemistry of ozone production, NO_x emissions lead to both the formation and destruction of ozone, depending on the relative quantities of NO_x, VOC, and ozone catalysts such as the OH and HO_2 radicals. In areas dominated by fresh emissions of NO_x, ozone catalysts are removed via the production of nitric acid which slows the ozone formation rate. Because NO_x 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 "NO_x 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 NO_x control is beneficial.[128]

In the context of ozone disbenefits, some have postulated that present-day weekend conditions serve as a demonstration of the effects of future NO_x reduction strategies because NO_x 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.[129, 130] There are other hypotheses for the cause of the "weekend effect."[131] 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 NO_x 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. 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 NO_x could modify the conclusions regarding ozone changes in some areas. Second, recent work by CARB has indicated that model limitations and uncertainties may lead to overestimates of ozone disbenefits attributed to NO_x 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 design values, 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.

Based only on the reductions from today's rule, our modeling predicts that in 2020 and 2030 periodic ozone disbenefit would occur in up to five counties: Suffolk and Hampton Counties in Virginia, Cook County in Illinois, Lake County in Indiana, and San Bernardino County in California. Despite these localized increases, the net ozone impact of the rule nationally is positive for the majority of the analysis metrics as described in section 2.2.4.1 above.

Historically, NO_x reductions have been very successful at reducing regional/national ozone levels. 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, NO_x 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 disbenefit. 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 NO_x reductions would reduce both ozone and PM [132] . EPA believes that a balanced air quality management approach that includes NO_x 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.[133] 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.

2.2.4.2 Ozone Air Quality Modeling Methodology

To model the ozone air quality benefits of this rule we also used the CMAQ model. CMAQ simulates the numerous physical and chemical processes involved in the formation, transport, and destruction of ozone. This model is commonly used in developing attainment demonstration State Implementation Plans as well as for estimating the ozone reductions expected to occur from a reduction in emitted pollutants. The model was applied for two separate domains: a) a 36 km continental U.S. domain as described in Section 2.1.5, and b) a smaller easter U.S. grid with a grid resolution of 12 km.

For ozone modeling results over the western U.S. the 36 km modeling results were used, but only for those periods within the months from May to October. Over the eastern U.S. we utilized two periods of episodic modeling to generate the projections: June 15-30, 2001 and July 15–August 10, 2001. Model configurations for the finer-scale episodic modeling was identical to that described in Section 2.1.5.2 except for the use of finer-scale MM5 meteorological inputs and that the boundary conditions were taken from the appropriate 36 km continental U.S. simulations.

2.2.5 Environmental Effects of Ozone Pollution

There are a number of public welfare effects associated with the presence of ozone in the ambient air.[134] In this section we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

2.2.5.1 Impacts on Vegetation

The Air Quality Criteria Document for Ozone and related Photochemical Oxidants notes that "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant. Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake".[135] Once sufficient levels of ozone, a highly reactive substance, (or its reaction products) reaches the interior of plant cells, it can inhibit or damage 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.[136,137] This damage is commonly manifested as visible foliar injury such as chlorotic or necrotic spots, increased leaf senescence (accelerated leaf aging) and/or reduced photosynthesis. All these effects reduce a plant's capacity to form carbohydrates, which are the primary form of energy used by plants.[138] 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. Furthermore, there is 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.[139,140]

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even lower concentrations experienced for a longer duration have the potential to create chronic stress on sensitive vegetation. 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).[141,142,143] 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.[144]

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 consistently toxic for all plants. The next few paragraphs present additional information on ozone damage to trees, ecosystems, agronomic crops and urban ornamentals.

Ozone also has been conclusively shown to cause discernible injury to forest trees.[145,146] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts. Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[147, 148]

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 impacts 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.[149] In most instances, responses to chronic or recurrent exposure in forested ecosystems are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[150,151,152] 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.

Laboratory and field experiments have also 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 Unites States."[153] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[154, 155, 156]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels. 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.[157] This is therefore a potentially costly environmental effect. However, 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 analysis has been conducted.

2.3 Air Toxics

People experience elevated risk of cancer and other noncancer health effects from exposure to air toxics. Mobile sources are responsible for a significant portion of this risk. According to the National Air Toxic Assessment (NATA) for 1999, mobile sources were responsible for 44 percent of outdoor toxic emissions and almost 50 percent of the cancer risk. Benzene is the largest contributor to cancer risk of all 133 pollutants quantitatively assessed in the 1999 NATA. Mobile sources were responsible for 68 percent of benzene emissions in 1999. In response, EPA has proposed a series of mobile source and fuel controls that address this serious problem.[L] Although the 1999 NATA did not quantify

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[L] U.S. EPA (2006). Control of Hazardous Air Pollutants From Mobile Sources. 71 FR 15804; March 29, 2006.

cancer risks associated with exposure to this diesel exhaust, EPA has concluded that diesel exhaust ranks with the other air toxic substances that the national-scale assessment suggests pose the greatest relative risk.

At the same time, nearly the entire U.S. population was exposed to an average level of air toxics that has the potential for adverse respiratory health effects (noncancer). This will continue to be the case in 2030, even though toxics levels will be lower. Mobile sources were responsible for 74 percent of the noncancer (respiratory) risk from outdoor air toxics in 1999. The majority of this risk was from acrolein, and formaldehyde also contributed to the risk of respiratory health effects. Mobile sources will continue to be responsible for the majority of noncancer risk from outdoor air toxics in 2030. Although not included in NATA's estimates of noncancer risk, PM from gasoline and diesel mobile sources contribute significantly to the health effects associated with ambient PM.

It should be noted that the NATA modeling framework has a number of limitations which prevent its use as the sole basis for setting regulatory standards. These limitations and uncertainties are discussed on the 1999 NATA website.[158] Even so, this modeling framework is very useful in identifying air toxic pollutants and sources of greatest concern, setting regulatory priorities, and informing the decision making process.

The following section provides an overview of air toxics which are associated with nonroad engines including locomotive and marine diesel engines and provides a discussion of the health risks associated with each air toxic.

2.3.1 Diesel Exhaust PM

Locomotive and marine diesel engine $PM_{2.5}$ emissions include diesel exhaust (DE), a complex mixture comprised of carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic including aldehydes, benzene and 1,3-butadiene. The diesel particulate matter (DPM) present in diesel exhaust consists of fine particles (< 2.5µm), including a subgroup with a large number of ultrafine particles (< 0.1 µm). These particles have large surface area which makes them an excellent medium for adsorbing organics as well as their small size makes them highly respirable and able to reach the deep lung. Many of the organic compounds present on the particles and in the gases are individually known to have mutagenic and carcinogenic properties. Diesel exhaust varies significantly in chemical composition and particle sizes between different engine types (heavy-duty, light-duty), engine operating conditions (idle, accelerate, decelerate), and fuel formulations (high/low sulfur fuel).[159] Also, there are emission differences between on-road and nonroad engines because the nonroad engines are generally of older technology. This is especially true for locomotive and marine diesel engines.

After emission from the tailpipe, diesel exhaust undergoes dilution as well as chemical and physical changes in the atmosphere. The lifetime for some of the compounds present in diesel exhaust ranges from hours to days. Although the 1999 National-Scale Air Toxics Assessment (NATA) did not quantify cancer risks associated with exposure to this pollutant, EPA has concluded that diesel exhaust ranks with the other air toxic substances that the national-scale assessment suggests pose the greatest relative risk. Following is a discussion of the health risks associated with diesel exhaust.

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.

2.3.1.1 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.

EPA's 2002 final "Health Assessment Document for Diesel Engine Exhaust" (the EPA Diesel HAD classified diesel exhaust as likely to be carcinogenic to humans by inhalation at environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines.[160,161] In accordance with earlier EPA guidelines, diesel exhaust would be similarly classified as a probable human carcinogen (Group B1). [162,163] 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.[164, 165,166,167,168] The Health Effects Institute has also made numerous studies and report on the potential carcinogenicity of diesel exhaust.[169, 170, 171] Numerous animal and bioassay/genotoxic tests have been done on diesel exhaust.[172, 173] Also, case-control and cohort studies have been conducted on railroad engine exposures[174, 175,176] in addition to studies on truck workers. [177, 178,179, 180] Also, there are numerous other epidemiologic studies including some studying mine workers and fire fighters. [181, 182]

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." In any case, the diesel technology used for locomotive and marine diesel engines typically lags that used for nonroad engines which have been subject to PM standards since 1998, thus it is reasonable to assume that the hazards identified from older technologies may be largely applicable to locomotive and marine engines.

For the Diesel HAD, EPA reviewed 22 epidemiologic studies on the subject of the carcinogenicity of workers exposed to diesel exhaust in various occupations, finding increased lung cancer risk, although not always statistically significant, in 8 out of 10 cohort studies and 10 out of 12 case-control studies within several industries, including railroad workers. Relative risk for lung cancer associated with exposure ranged from 1.2 to 1.5, although a few studies show relative risks as high as 2.6. Additionally, the Diesel HAD also relied on two independent meta-analyses, which examined 23 and 30 occupational studies respectively, which found statistically significant increases in smoking-adjusted relative lung cancer risk associated with diesel exhaust, of 1.33 to 1.47. These meta-analyses demonstrate the effect of pooling many studies and in this case show the positive relationship between diesel exhaust exposure and lung cancer across a variety of diesel exhaust-exposed occupations. [183,184,185]

Retrospective health studies of railroad workers have played an important part in finding that diesel exhaust is a likely human carcinogen. Key evidence of the diesel exhaust exposure linkage to lung cancer comes from two retrospective case-control studies of railroad workers. The Garshick railroad study [186] looked at more than 55,000 railroad workers post-1959 which coincided with the widespread dieselization of the railroads. The study found that the risk of lung cancer increased with increasing duration of employment, and that the youngest workers had the highest risk of dying. The second railroad study authored by Swanson et al. [187] found statistically significant excess risks, when adjusted for age, smoking, and race, among railroad workers employed for more than 10 years and heavy truck drivers employed for more than 20 years. In addition, a 1988 industrial hygiene study documented the increased lung cancer risks associated with different railroad worker job classifications. [188] Thirty-nine job titles were originally identified and were then collapsed, for statistical analyses, into 5 categories including clerks, signal maintainers, engineers/firers, brakers/conductors/hostlers, and shop workers. The study documented that those in closest contact with diesel exhaust exhibited the highest level of lung cancer risk. Train workers (engineers/firers etc.) had the highest risk, shop workers an intermediate level, and clerks the lowest lung cancer risk.

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 $\mu g/m^3$. 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. An exploratory analysis was used to characterize a possible risk range 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 ratios 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 µg/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 versus 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 µg/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 judgment. 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 no evidence is available on this point. As discussed in the Diesel HAD, there is a relatively small difference between some occupational studies where increased lung cancer risk is reported and concentrations sometimes seen in ambient settings.

EPA recently assessed air toxic emissions and their associated risk (the National-Scale Air Toxics Assessment or NATA for 1996 and 1999), and we concluded that diesel exhaust ranks with substances that the national-scale assessment suggests pose the greatest relative risk.[189,190] This national assessment estimates average population inhalation exposures to diesel PM for nonroad as well as on-highway sources. These are the sum of ambient levels in various locations weighted by the amount of time people spend in each of the locations. The EPA Diesel HAD states that use of the 1996 NATA exposure estimates instead of the 0.8 µg/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 from locomotive and marine engines present public health issues of concern to this proposal.

2.3.1.2 Other Health Effects of Diesel Exhaust

Noncancer health effects of acute and chronic exposure to 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, which 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.[191], [192], [193],[194] The diesel RfC is based on a "no observable adverse effect" level of 144 µg/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 µg/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. The EPA Diesel HAD states, "With DPM [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing DE [diesel exhaust] noncancer database to identify all of the pertinent DE-caused noncancer health hazards" (p. 9-19).

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.[195,196,197] 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.

Diesel exhaust has been shown to cause serious noncancer effects in occupational exposure studies. One recent study [198] of a small group of railroad workers and electricians found that exposure to diesel exhaust resulted in neurobehavioral impairments in one or more areas including reaction time, balance, blink reflex latency, verbal recall, and color vision confusion indices. Pulmonary function tests also showed that 10 of the 16 workers had airway obstruction and another group of 10 of 16 workers had chronic bronchitis, chest pain, tightness, and hyperactive airways. Finally, a variety of studies have been published subsequent to the completion of the Diesel HAD. One such study, published in 2006[199] found that railroad engineers and conductors with diesel exhaust exposure from operating trains had an increased incidence of chronic obstructive pulmonary disease (COPD) mortality. The odds of COPD mortality increased with years on the job so that those who had worked more than 16 years as an engineer or conductor after 1959 had an increased risk of 1.61 (95% confidence interval, 1.12 - 2.30). EPA is assessing the significance of this study within the context of the broader literature.

The Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses the EPA's annual NAAQS of 15 $\mu g/m^3$. 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 $PM_{2.5}$ NAAQS is designed to provide protection from the non-cancer and premature mortality effects of $PM_{2.5}$ as a whole, of which diesel PM is a constituent.

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 mobile source exhaust including diesels in particular, that provide additional evidence for the need for significant emission reductions from locomotive and marine 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.

2.3.1.3 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.

2.3.1.3.1 *Toxics Modeling and Methods*

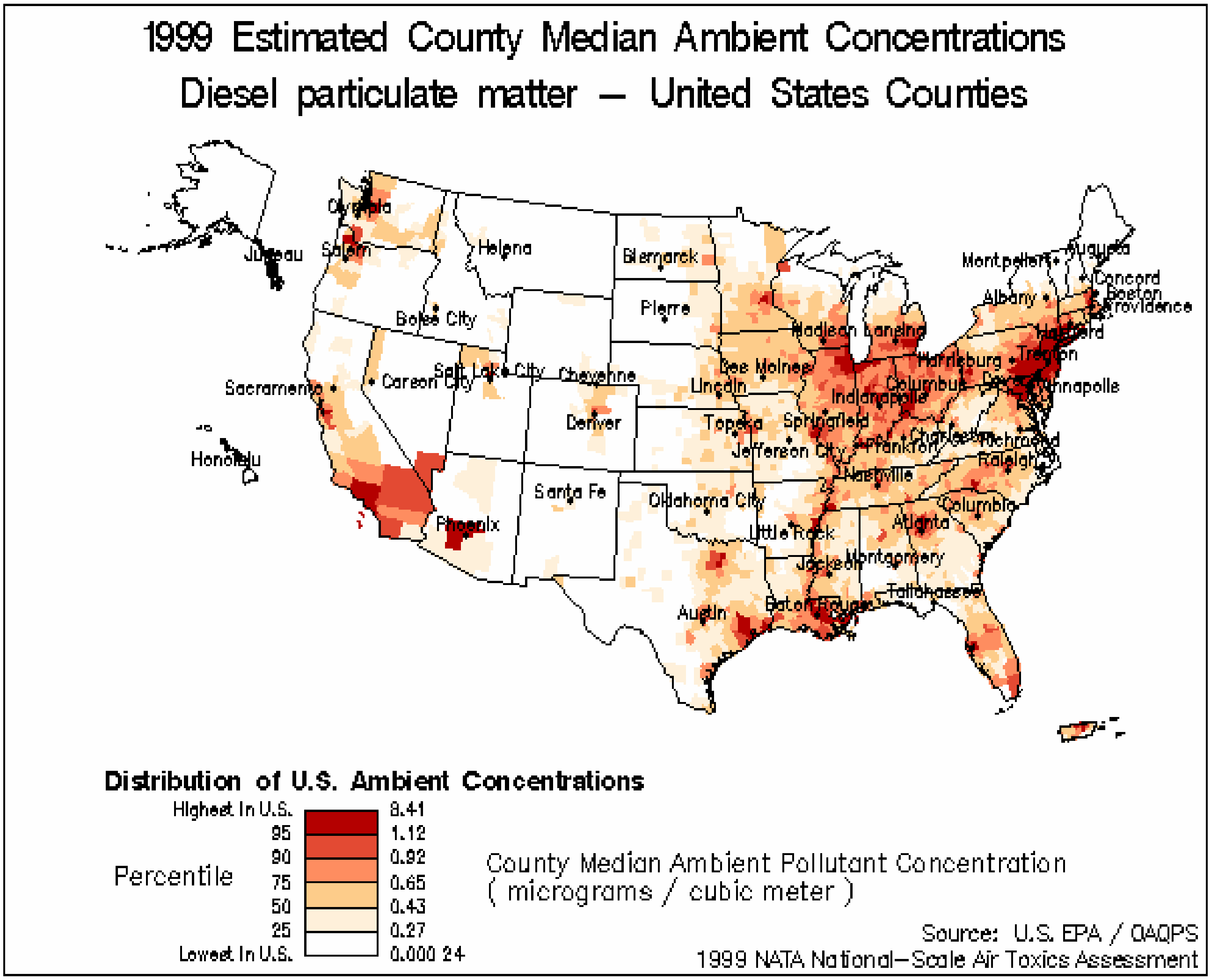
In addition to the general ambient PM modeling conducted for this proposal, diesel PM concentrations for 1999 were recently estimated as part of the second National-Scale Air Toxics Assessment (NATA; EPA, 2006). Ambient impacts of mobile source emissions were predicted using the Assessment System for Population Exposure Nationwide (ASPEN) dispersion model.

From the NATA 1999 modeling, overall medium annual national ambient diesel PM levels of .91 $\mu g/m^3$ were calculated with a medium of 1.06 in urban counties and 0.43 in rural counties. Table 2-8 below summarizes the distribution of medium ambient concentrations to diesel PM at the national scale. Over half, 62 percent, of the diesel PM and diesel exhaust organic gases can be attributed to nonroad diesels. A map of county median ambient concentrations is provided in Figure 2-8. While the high median concentrations are clustered in the Northeast, Great Lake States California, and the Gulf Coast States, areas of high median concentrations are distributed throughout the U.S.

Table 2-8 Distribution of Median Ambient Concentrations of Diesel PM at the National Scale in the 1999 NATA Assessment.

	Nationwide ($\mu g/m^3$)	Urban ($\mu g/m^3$)	Rural ($\mu g/m^3$)
5th Percentile	0.21	0.22	0.08
25th Percentile	0.54	.70	0.28
Medium	0.91	1.06	0.43
75th Percentile	1.41	1.56	0.62
95th Percentile	2.91	3.21	.96
Onroad Contribution to Mean	0.43	0.49	0.20
Nonroad Contribution to Mean	0.78	0.90	0.28

Figure 2-10 Estimated County Median Ambient Concentration of Diesel Particulate Matter



2.3.1.4 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 in those locations. The major difference between ambient levels of diesel particulate and exposure levels for diesel particulate is that exposure accounts for a person moving from location to location, proximity to the emission source, and whether the exposure occurs in an enclosed environment.

2.3.1.4.1 *Occupational Exposures*

Occupational exposures to diesel exhaust from mobile sources, including locomotive engines and marine diesel engines, can be several orders of magnitude greater than typical exposures in the non-occupationally exposed population.

Over the years, diesel particulate exposures have been measured for a number of occupational groups resulting in a wide range of exposures from 2 to 1,280 µg/m^3 for a variety of occupations. Studies have shown that miners and railroad workers typically have higher diesel exposure levels than other occupational groups studied, including firefighters, truck dock workers, and truck drivers (both short and long haul).[200] A 1988 study[201] estimated that U.S. railroad workers received an estimated occupational exposure/concentration of between 39 -191 µg/m^3 which resulted in an equivalent environmental exposure of 8-40 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 vehicles including locomotive and marine diesel engines.

2.3.1.4.1.1 Elevated Concentrations and Ambient Exposures in Mobile Source-Impacted Areas

While occupational studies indicate that those in closest proximity to diesel exhaust experience the greatest health effects, recent studies are showing that human populations living near large diesel emission sources such as major roadways, [202] rail yards and marine ports [203] are also likely to experience greater diesel exhaust exposure levels than the overall population putting them at greater health risks.

Regions immediately downwind of rail yards and marine ports may experience elevated ambient concentrations of directly-emitted $PM_{2.5}$ from diesel engines. Due to the unique nature of rail yards and marine ports, emissions from a large number of diesel engines are concentrated in a small area. Furthermore, emissions occur at or near ground level, allowing emissions of diesel engines to reach nearby receptors without fully mixing with background air.

A recent study conducted by the California Air Resources Board (CARB) examined the air quality impacts of railroad operations at the J.R. Davis Rail Yard, the largest rail facility in the western United States. [204] The yard occupies 950 acres along a one-quarter mile wide and four mile long section of land in Roseville, CA. The study developed an emissions inventory for the facility for the year 2000 and modeled ambient concentrations of diesel PM using a well-accepted dispersion model (ISCST3). The study found substantially elevated concentrations in an area 5,000 meters from the facility, with higher concentrations closer to the rail yard. Using local meteorological data, annual average contributions from the rail yard to ambient diesel PM concentrations under prevailing wind conditions were 1.74, 1.18, 0.80, and 0.25 µg/m^3 at receptors located 200, 500, 1000, and 5000 meters from the yard, respectively. Several tens of thousands of people live within the area experiencing substantial increases in annual average ambient $PM_{2.5}$ as a result of emissions from the yard.

Another study from CARB evaluated air quality impacts of diesel engine emissions within the Ports of Long Beach and Los Angeles in California, one of the largest ports in the U.S. [205] Like the earlier rail yard study, the port study employed the ISCST3 dispersion model. Also using local meteorological data, annual average concentrations were substantially elevated over an area exceeding 200,000 acres. Because they are located near heavily-populated areas, the modeling indicated that over 700,000 people lived in areas with at least 0.3 µg/m^3 of port-related diesel PM in ambient air, about 360,000 people lived in areas with at least 0.6 µg/m^3 of diesel PM, and about 50,000 people lived in areas with at least 1.5 µg/m^3 of ambient diesel PM directly from the port. Figure 2-11 provides an aerial shot of the Port of Long beach and Los Angeles in California.

Figure 2-11 Aerial Shot – Port of LA and Long Beach, California

While these studies focus on two large marine port and one large rail yard facility, these studies do highlight the substantial contribution these facilities make to elevated ambient concentrations in large, densely populated areas.

We have recently initiated a study to better understand the populations that are living near rail yards and marine ports. As part of the study, a computer geographic information system (GIS) is being used to identify the locations and property boundaries of a sampling of these facilities nationally, and to determine the size and demographic characteristics of the population living near these facilities. We anticipate that the results of this study will be complete in early 2007 and we intend to add this report to the public docket in advance of the final rulemaking. Figure 2.-12 to 2.-14 provides a sampling of aerial photos of the rail yards and marine ports that are part of this study.

Figure 2-12   2006 aerial photo Port of Cleveland, Cleveland Ohio

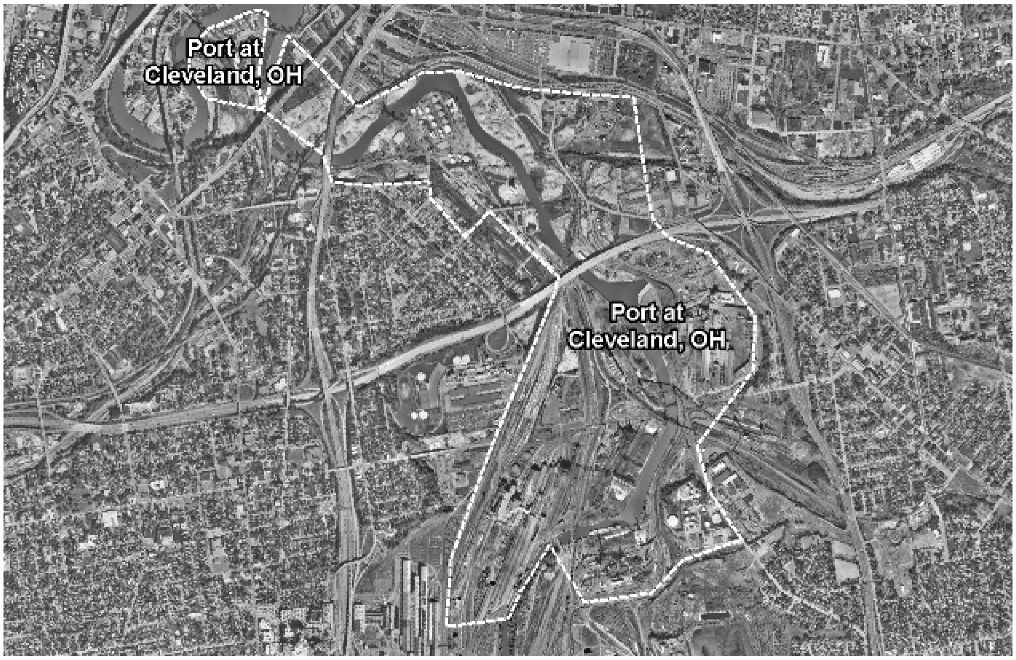


Figure 2-13 2006 aerial photo Argentine Rail Yard, Kansas City, Missouri

Figure 2-14. 2006 aerial photo DeButts Rail Yard, Chattanooga, Tennessee

2.4 Gaseous Air Toxics—benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, POM, naphthalene

Locomotive and marine diesel engine emissions contribute to ambient levels of other air toxics known or suspected as human or animal carcinogens, or that have non-cancer health effects. These other compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. All of these compounds, except acetaldehyde, were identified as national or regional risk drivers in the 1999 National-Scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources. Table 2 – 9 provides the mobile source contributions associated with these compounds. The reductions in locomotive and marine diesel engine emissions proposed in this rulemaking would help reduce exposure to these harmful substances.

Table 2-9 Mobile Source Contribution to 1999 NATA Risk Drivers

1999 NATA Risk Drivers	Percent Contribution from ALL Mobile Sources	Percent Contribution for Non-road Mobile Sources
Benzene	68%	19%
1,2-Butadiene	58%	17%
Formaldehyde	47%	20%
Acrolein	25%	11%

Polycyclic organic matter (POM)*	6%	3%
Naphthalene	27%	6%
Diesel PM and Diesel exhaust organic gases	100%	62%

✶This POM inventory includes the 15 POM compounds: benzo[b]fluoranthene, benz[a]anthracene, indeno(1,2,3-c,d)pyrene,benzo[k]fluoranthene, chrysene, benzo[a]pyrene, dibenz(a,h)anthracene,anthracene, pyrene, benzo(g,h,i)perylene, fluoranthene, acenaphthylene, phenanthrene, fluorine, and acenaphthene.

Air toxics can cause a variety of cancer and noncancer health effects. A number of the mobile source air toxic pollutants described in this section are known or likely to pose a cancer hazard in humans. Many of these compounds also cause adverse noncancer health effects resulting from chronic,[206] subchronic,[207] or acute[208] inhalation exposures. These include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems.

Benzene: The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[209, 210, 211] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggests a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[212, 213] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.214, [215] In addition, recent work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known. [216, 217, 218, 219] EPA's IRIS program has not yet evaluated these new data

1,3-Butadiene: EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[220, 221] 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; while there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 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.[222]

Formaldehyde: Since 1987, EPA has classified formaldehyde as a probable human carcinogen based on evidence in humans and in rats, mice, hamsters, and monkeys.[223] EPA's current IRIS summary provides an upper bound cancer unit risk estimate of 1.3x10^{-5} per µg/m^3. In other words, there is an estimated risk of about thirteen excess leukemia cases in one million people exposed to 1 µg/m^3 of formaldehyde over a lifetime. EPA is currently reviewing recently published epidemiological data. For instance, research conducted by the National Cancer Institute (NCI) found an increased risk of nasopharyngeal cancer and lymphohematopoietic malignancies such as leukemia among workers exposed to formaldehyde.[224, 225] NCI is currently performing an update of these studies. A recent National Institute of Occupational Safety and Health (NIOSH) study of garment workers also found increased risk of death due to leukemia among workers exposed to formaldehyde.[226] Extended follow-up of a cohort of British chemical workers did not find evidence of an increase in nasopharyngeal or lymphohematopoeitic cancers, but a continuing statistically significant excess in lung cancers was reported. [227]

Based on the developments of the last decade, in 2004, the working group of the International Agency for Research on Cancer (IARC) concluded that formaldehyde is carcinogenic to humans (Group 1), on the basis of sufficient evidence in humans and sufficient evidence in experimental animals—a higher classification than previous IARC evaluations. The Agency is currently conducting a reassessment of the human hazard and dose-response associated with formaldehyde.

In the past 15 years there has been substantial research on the inhalation dosimetry for formaldehyde in rodents and primates by the CIIT Centers for Health Research (formerly the Chemical Industry Institute of Toxicology), with a focus on use of rodent data for refinement of the quantitative cancer dose-response assessment.[228, 229,230 ,] CIIT's risk assessment of formaldehyde incorporated mechanistic and dosimetric information on formaldehyde. The risk assessment analyzed carcinogenic risk from inhaled formaldehyde using approaches that are consistent with EPA's draft guidelines for carcinogenic risk assessment. In 2001, Environment Canada relied on this cancer dose-response assessment in their assessment of formaldehyde. [231] In 2004, EPA also relied on this cancer unit risk estimate during the development of the plywood and composite wood products national emissions standards for hazardous air pollutants (NESHAPs). [232] In these rules, EPA concluded that the CIIT work represented the best available application of the available mechanistic and dosimetric science on the dose-response for portal of entry cancers due to formaldehyde exposures. EPA is reviewing the recent work cited above from the NCI and NIOSH, as well as the analysis by the CIIT Centers for Health Research and other studies, as part of a reassessment of the human hazard and dose-response associated with formaldehyde.

Formaldehyde exposure also causes a range of noncancer health effects, including irritation of the eyes (tearing of the eyes and increased blinking) and mucous membranes.

Acetaldehyde: Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[233] The primary acute effect of exposure to acetaldehyde vapors is irritation of the eyes, skin, and respiratory tract.[234] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

Acrolein: Acrolein is intensely irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation and congestion. EPA determined in

2003 using the 1999 draft cacner guidelines that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[235]

Polycyclic Organic Matter (POM): POM is generally defined as a large class of organic compounds which have multiple benzene rings and a boiling point greater than 100 degrees Celsius. 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. One of these compounds, naphthalene, is discussed separately below.

Recent studies have found that maternal exposures to PAHs, in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth as well as impaired cognitive development at age three.[236, 237] EPA has not yet evaluated these recent studies.

Naphthalene: Naphthalene is found in small quantities in gasoline and diesel fuels but is primarily a product of combustion. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust and evaporative emissions from mobile sources. EPA recently released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[238] The draft reassessment recently completed external peer review.[239] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[240] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[241]

In addition to reducing substantial amounts of NO_x and $PM_{2.5}$ emissions from locomotive and marine diesel engines the standards being proposed today would also reduce air toxics emitted from these engines thereby helping to mitigate some of the adverse health effects associated with operation of these engines.

Appendix 2A PM$_{2.5}$ Nonattainment

Table 2A PM$_{2.5}$ Nonattainment Areas and Populations (Data is current throughOctober 2006 and Population Numbers are from 2000 Census Data

County	Area Name	County NAWhole/Part	Design Value (µg/m^{3}_	Pop (2000)
ALABAMA				
Jackson Co	Chattanooga, AL-TN-GA	Part	16.1	1,578
Jefferson Co	Birmingham, AL	Whole	17.3	662,047
Shelby Co	Birmingham, AL	Whole	17.3	143,293
Walker Co	Birmingham, AL	Part	17.3	2,272
CALIFORNIA				
Fresno Co	San Joaquin Valley, CA	Whole	21.8	799,407
Kern Co	San Joaquin Valley, CA	Part	21.8	550,220
Kings Co	San Joaquin Valley, CA	Whole	21.8	129,461
Los Angeles Co	Los Angeles-South Coast Air Basin, CA	Part	27.8	9,222,280
Madera Co	San Joaquin Valley, CA	Whole	21.8	123,109
Merced Co	San Joaquin Valley, CA	Whole	21.8	210,554
Orange Co	Los Angeles-South Coast Air Basin, CA	Whole	27.8	2,846,289
Riverside Co	Los Angeles-South Coast Air Basin, CA	Part	27.8	1,194,859
San Bernardino Co	Los Angeles-South Coast Air Basin, CA	Part	27.8	1,330,159
San Joaquin Co	San Joaquin Valley, CA	Whole	21.8	563,598
Stanislaus Co	San Joaquin Valley, CA	Whole	21.8	446,997
Tulare Co	San Joaquin Valley, CA	Whole	21.8	368,021
CONNECTICUT				
Fairfield Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	882,567
New Haven Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	824,008
DELAWARE				
New Castle Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	500,265
DISTRICT OF COLUMBIA				
Entire District	Washington, DC-MD-VA	Whole	15.8	572,059
GEORGIA				
Barrow Co	Atlanta, GA	Whole	18	46,144
Bartow Co	Atlanta, GA	Whole	18	76,019
Bibb Co	Macon, GA	Whole	15.2	153,887
Carroll Co	Atlanta, GA	Whole	18	87,268
Catoosa Co	Chattanooga, AL-TN-GA	Whole	16.1	53,282
Cherokee Co	Atlanta, GA	Whole	18	141,903

County	Area Name	County NAWhole/Part	Design Value (µg/m^3_	Pop (2000)
Clayton Co	Atlanta, GA	Whole	18	236,517
Cobb Co	Atlanta, GA	Whole	18	607,751
Coweta Co	Atlanta, GA	Whole	18	89,215
De Kalb Co	Atlanta, GA	Whole	18	665,865
Douglas Co	Atlanta, GA	Whole	18	92,174
Fayette Co	Atlanta, GA	Whole	18	91,263
Floyd Co	Rome, GA	Whole	15.6	90,565
Forsyth Co	Atlanta, GA	Whole	18	98,407
Fulton Co	Atlanta, GA	Whole	18	816,006
Gwinnett Co	Atlanta, GA	Whole	18	588,448
Hall Co	Atlanta, GA	Whole	18	139,277
Heard Co	Atlanta, GA	Part	18	170
Henry Co	Atlanta, GA	Whole	18	119,341
Monroe Co	Macon, GA	Part	15.2	950
Newton Co	Atlanta, GA	Whole	18	62,001
Paulding Co	Atlanta, GA	Whole	18	81,678
Putnam Co	Atlanta, GA	Part	18	3,088
Rockdale Co	Atlanta, GA	Whole	18	70,111
Spalding Co	Atlanta, GA	Whole	18	58,417
Walker Co	Chattanooga, AL-TN-GA	Whole	16.1	61,053
Walton Co	Atlanta, GA	Whole	18	60,687
ILLINOIS				
Cook Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	5,376,741
DuPage Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	904,161
Grundy Co	Chicago-Gary-Lake County, IL-IN	Part	17.7	6,309
Kane Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	404,119
Kendall Co	Chicago-Gary-Lake County, IL-IN	Part	17.7	28,417
Lake Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	644,356
Madison Co	St. Louis, MO-IL	Whole	17.5	258,941
Mc Henry Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	260,077
Monroe Co	St. Louis, MO-IL	Whole	17.5	27,619
Randolph Co	St. Louis, MO-IL	Part	17.5	3,627
St Clair Co	St. Louis, MO-IL	Whole	17.5	256,082
Will Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	502,266
INDIANA				

County	**Area Name**	**County NAWhole/Part**	**Design Value (µg/m^{3}_**	**Pop (2000)**
Clark Co	Louisville, KY-IN	Whole	16.9	96,472
Dearborn Co	Cincinnati-Hamilton, OH-KY-IN	Part	17.8	10,434
Dubois Co	Evansville, IN	Whole	16.2	39,674
Floyd Co	Louisville, KY-IN	Whole	16.9	70,823
Gibson Co	Evansville, IN	Part	16.2	3,698
Hamilton Co	Indianapolis, IN	Whole	16.7	182,740
Hendricks Co	Indianapolis, IN	Whole	16.7	104,093
Jefferson Co	Louisville, KY-IN	Part	16.9	16,770
Johnson Co	Indianapolis, IN	Whole	16.7	115,209
Lake Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	484,564
Marion Co	Indianapolis, IN	Whole	16.7	860,454
Morgan Co	Indianapolis, IN	Whole	16.7	66,689
Pike Co	Evansville, IN	Part	16.2	4,633
Porter Co	Chicago-Gary-Lake County, IL-IN	Whole	17.7	146,798
Spencer Co	Evansville, IN	Part	16.2	5,092
Vanderburgh Co	Evansville, IN	Whole	16.2	171,922
Warrick Co	Evansville, IN	Whole	16.2	52,383
KENTUCKY				
Boone Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	85,991
Boyd Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	49,752
Bullitt Co	Louisville, KY-IN	Whole	16.9	61,236
Campbell Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	88,616
Jefferson Co	Louisville, KY-IN	Whole	16.9	693,604
Kenton Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	151,464
Lawrence Co	Huntington-Ashland, WV-KY-OH	Part	17.2	1,050
MARYLAND				
Anne Arundel Co	Baltimore, MD	Whole	16.6	489,656
Baltimore (City)	Baltimore, MD	Whole	16.6	651,154
Baltimore Co	Baltimore, MD	Whole	16.6	754,292
Carroll Co	Baltimore, MD	Whole	16.6	150,897
Charles Co	Washington, DC-MD-VA	Whole	15.8	120,546
Frederick Co	Washington, DC-MD-VA	Whole	15.8	195,277
Harford Co	Baltimore, MD	Whole	16.6	218,590
Howard Co	Baltimore, MD	Whole	16.6	247,842
Montgomery Co	Washington, DC-MD-VA	Whole	15.8	873,341

County	**Area Name**	**County NAWhole/Part**	**Design Value (µg/m^3_**	**Pop (2000)**
Prince George's Co	Washington, DC-MD-VA	Whole	15.8	801,515
Washington Co	Martinsburg, WV-Hagerstown, MD	Whole	16.3	131,923
MICHIGAN				
Livingston Co	Detroit-Ann Arbor, MI	Whole	19.5	156,951
Macomb Co	Detroit-Ann Arbor, MI	Whole	19.5	788,149
Monroe Co	Detroit-Ann Arbor, MI	Whole	19.5	145,945
Oakland Co	Detroit-Ann Arbor, MI	Whole	19.5	1,194,156
St Clair Co	Detroit-Ann Arbor, MI	Whole	19.5	164,235
Washtenaw Co	Detroit-Ann Arbor, MI	Whole	19.5	322,895
Wayne Co	Detroit-Ann Arbor, MI	Whole	19.5	2,061,162
MISSOURI				
Franklin Co	St. Louis, MO-IL	Whole	17.5	93,807
Jefferson Co	St. Louis, MO-IL	Whole	17.5	198,099
St Charles Co	St. Louis, MO-IL	Whole	17.5	283,883
St Louis	St. Louis, MO-IL	Whole	17.5	348,189
St Louis Co	St. Louis, MO-IL	Whole	17.5	1,016,315
MONTANA				
Lincoln Co	Libby, MT	Part	16.2	2,626
NEW JERSEY				
Bergen Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	884,118
Burlington Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	423,394
Camden Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	508,932
Essex Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	793,633
Gloucester Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	254,673
Hudson Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	608,975
Mercer Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	350,761
Middlesex Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	750,162
Monmouth Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	615,301
Morris Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	470,212
Passaic Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	489,049
Somerset Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	297,490
Union Co	New York-N. New Jersey-	Whole	17.7	522,541

County	Area Name	County NAWhole/Part	Design Value (µg/m^3_	Pop (2000)
	Long Island, NY-NJ-CT			
New York				
Bronx Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,332,650
Kings Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	2,465,326
Nassau Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,334,544
New York Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,537,195
Orange Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	341,367
Queens Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	2,229,379
Richmond Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	443,728
Rockland Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	286,753
Suffolk Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	1,419,369
Westchester Co	New York-N. New Jersey-Long Island, NY-NJ-CT	Whole	17.7	923,459
NORTH CAROLINA				
Catawba Co	Hickory, NC	Whole	15.5	141,685
Davidson Co	Greensboro-Winston Salem-High Point, NC	Whole	15.8	147,246
Guilford Co	Greensboro-Winston Salem-High Point, NC	Whole	15.8	421,048
OHIO				
Adams Co	Huntington-Ashland, WV-KY-OH	Part	17.2	2,374
Ashtabula Co	Cleveland-Akron-Lorain, OH	Part	18.3	23,239
Belmont Co	Wheeling, WV-OH	Whole	15.7	70,226
Butler Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	332,807
Clark Co	Dayton-Springfield, OH	Whole	15.2	144,742
Clermont Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	177,977
Coshocton Co	Columbus, OH	Part	16.7	1,286
Cuyahoga Co	Cleveland-Akron-Lorain, OH	Whole	18.3	1,393,978
Delaware Co	Columbus, OH	Whole	16.7	109,989
Fairfield Co	Columbus, OH	Whole	16.7	122,759
Franklin Co	Columbus, OH	Whole	16.7	1,068,978
Gallia Co	Huntington-Ashland, WV-KY-OH	Part	17.2	3,625
Greene Co	Dayton-Springfield, OH	Whole	15.2	147,886
Hamilton Co	Cincinnati-Hamilton, OH-KY-	Whole	17.8	845,303

County	Area Name	County NAWhole/Part	Design Value (µg/m^3_	Pop (2000)
	IN			
Jefferson Co	Steubenville-Weirton, OH-WV	Whole	17.8	73,894
Lake Co	Cleveland-Akron-Lorain, OH	Whole	18.3	227,511
Lawrence Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	62,319
Licking Co	Columbus, OH	Whole	16.7	145,491
Lorain Co	Cleveland-Akron-Lorain, OH	Whole	18.3	284,664
Medina Co	Cleveland-Akron-Lorain, OH	Whole	18.3	151,095
Montgomery Co	Dayton-Springfield, OH	Whole	15.2	559,062
Portage Co	Cleveland-Akron-Lorain, OH	Whole	18.3	152,061
Scioto Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	79,195
Stark Co	Canton-Massillon, OH	Whole	17.3	378,098
Summit Co	Cleveland-Akron-Lorain, OH	Whole	18.3	542,899
Warren Co	Cincinnati-Hamilton, OH-KY-IN	Whole	17.8	158,383
Washington Co	Parkersburg-Marietta, WV-OH	Whole	16	63,251
PENNSYLVANIA				
Allegheny Co	Liberty-Clairton, PA	Part	21.2	21,600
Allegheny Co	Pittsburgh-Beaver Valley, PA	Part	16.9	1,260,066
Armstrong Co	Pittsburgh-Beaver Valley, PA	Part	16.9	3,691
Beaver Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	181,412
Berks Co	Reading, PA	Whole	16.4	373,638
Bucks Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	597,635
Butler Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	174,083
Cambria Co	Johnstown, PA	Whole	15.8	152,598
Chester Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	433,501
Cumberland Co	Harrisburg-Lebanon-Carlisle, PA	Whole	15.7	213,674
Dauphin Co	Harrisburg-Lebanon-Carlisle, PA	Whole	15.7	251,798
Delaware Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	550,864
Greene Co	Pittsburgh-Beaver Valley, PA	Part	16.9	1,714
Indiana Co	Johnstown, PA	Part	15.8	11,833
Lancaster Co	Lancaster, PA	Whole	17	470,658
Lawrence Co	Pittsburgh-Beaver Valley, PA	Part	16.9	1,198
Lebanon Co	Harrisburg-Lebanon-Carlisle, PA	Whole	15.7	120,327
Montgomery Co	Philadelphia-Wilmington, PA-NJ-DE	Whole	16.2	750,097
Philadelphia Co	Philadelphia-Wilmington, PA-	Whole	16.2	1,517,550

County	**Area Name**	**County NAWhole/Part**	**Design Value (µg/m^3_**	**Pop (2000)**
	NJ-DE			
Washington Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	202,897
Westmoreland Co	Pittsburgh-Beaver Valley, PA	Whole	16.9	369,993
York Co	York, PA	Whole	17	381,751
TENNESSEE				
Anderson Co	Knoxville, TN	Whole	16.4	71,330
Blount Co	Knoxville, TN	Whole	16.4	105,823
Hamilton Co	Chattanooga, AL-TN-GA	Whole	16.1	307,896
Knox Co	Knoxville, TN	Whole	16.4	382,032
Loudon Co	Knoxville, TN	Whole	16.4	39,086
Roane Co	Knoxville, TN	Part	16.4	737
VIRGINIA				
Alexandria	Washington, DC-MD-VA	Whole	15.8	128,283
Arlington Co	Washington, DC-MD-VA	Whole	15.8	189,453
Fairfax	Washington, DC-MD-VA	Whole	15.8	21,498
Fairfax Co	Washington, DC-MD-VA	Whole	15.8	969,749
Falls Church	Washington, DC-MD-VA	Whole	15.8	10,377
Loudoun Co	Washington, DC-MD-VA	Whole	15.8	169,599
Manassas	Washington, DC-MD-VA	Whole	15.8	35,135
Manassas Park	Washington, DC-MD-VA	Whole	15.8	10,290
Prince William Co	Washington, DC-MD-VA	Whole	15.8	280,813
WEST VIRGINIA				
Berkeley Co	Martinsburg, WV-Hagerstown, MD	Whole	16.3	75,905
Brooke Co	Steubenville-Weirton, OH-WV	Whole	17.8	25,447
Cabell Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	96,784
Hancock Co	Steubenville-Weirton, OH-WV	Whole	17.8	32,667
Kanawha Co	Charleston, WV	Whole	17.1	200,073
Marshall Co	Wheeling, WV-OH	Whole	15.7	35,519
Mason Co	Huntington-Ashland, WV-KY-OH	Part	17.2	2,774
Ohio Co	Wheeling, WV-OH	Whole	15.7	47,427
Pleasants Co	Parkersburg-Marietta, WV-OH	Part	16	1,675
Putnam Co	Charleston, WV	Whole	17.1	51,589
Wayne Co	Huntington-Ashland, WV-KY-OH	Whole	17.2	42,903
Wood Co	Parkersburg-Marietta, WV-OH	Whole	16	87,986
TOTAL	**208 Counties**			88,394,361

Appendix 2B: Current 8-Hour Ozone Nonattainment Areas

Table 2B 8-Hour Ozone Nonattainment Areas and Populations (Data is current through October 2006 and Population Numbers are from 2000 Census Data)

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
	NY	Subpart 1	Albany Co	W	294,565
Albany-Schenectady-Troy Area	NY	Subpart 1	Greene Co	W	48,195
Albany-Schenectady-Troy Area	NY	Subpart 1	Montgomery Co	W	49,708
Albany-Schenectady-Troy Area	NY	Subpart 1	Rensselaer Co	W	152,538
Albany-Schenectady-Troy Area	NY	Subpart 1	Saratoga Co	W	200,635
Albany-Schenectady-Troy Area	NY	Subpart 1	Schenectady Co	W	146,555
Albany-Schenectady-Troy Area	NY	Subpart 1	Schoharie Co	W	31,582
Allegan County Area	MI	Subpart 1	Allegan Co	W	105,665
Allentown-Bethlehem-Easton Area	PA	Subpart 1	Carbon Co	W	58,802
Allentown-Bethlehem-Easton Area	PA	Subpart 1	Lehigh Co	W	312,090
Allentown-Bethlehem-Easton Area	PA	Subpart 1	Northampton Co	W	267,066
Altoona Area	PA	Subpart 1	Blair Co	W	129,144
Amador and Calaveras Counties (Central Mountain Counties) Area	CA	Subpart 1	Amador Co	W	35,100
Amador and Calaveras Counties (Central Mountain Counties) Area	CA	Subpart 1	Calaveras Co	W	40,554
Atlanta Area	GA		Barrow Co	W	46,144
Atlanta Area	GA	Subpart 2/Marginal	Bartow Co	W	76,019
Atlanta Area	GA	Subpart 2/Marginal	Carroll Co	W	87,268
Atlanta Area	GA	Subpart 2/Marginal	Cherokee Co	W	141,903
Atlanta Area	GA	Subpart 2/Marginal	Clayton Co	W	236,517
Atlanta Area	GA	Subpart 2/Marginal	Cobb Co	W	607,751
Atlanta Area	GA	Subpart 2/Marginal	Coweta Co	W	89,215
Atlanta Area	GA	Subpart 2/Marginal	De Kalb Co	W	665,865
Atlanta Area	GA	Subpart 2/Marginal	Douglas Co	W	92,174
Atlanta Area	GA	Subpart 2/Marginal	Fayette Co	W	91,263
Atlanta Area	GA	Subpart 2/Marginal	Forsyth Co	W	98,407
Atlanta Area	GA	Subpart 2/Marginal	Fulton Co	W	816,006
Atlanta Area	GA	Subpart 2/Marginal	Gwinnett Co	W	588,448
Atlanta Area	GA	Subpart 2/Marginal	Hall Co	W	139,277
Atlanta Area	GA	Subpart 2/Marginal	Henry Co	W	119,341
Atlanta Area	GA	Subpart 2/Marginal	Newton Co	W	62,001
Atlanta Area	GA	Subpart 2/Marginal	Paulding Co	W	81,678

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Atlanta Area	GA	Subpart 2/Marginal	Rockdale Co	W	70,111
Atlanta Area	GA	Subpart 2/Marginal	Spalding Co	W	58,417
Atlanta Area	GA	Subpart 2/Marginal	Walton Co	W	60,687
Baltimore Area	MD	Subpart 2/Moderate	Anne Arundel Co	W	489,656
Baltimore Area	MD	Subpart 2/Moderate	Baltimore (City)	W	651,154
Baltimore Area	MD	Subpart 2/Moderate	Baltimore Co	W	754,292
Baltimore Area	MD	Subpart 2/Moderate	Carroll Co	W	150,897
Baltimore Area	MD	Subpart 2/Moderate	Harford Co	W	218,590
Baltimore Area	MD	Subpart 2/Moderate	Howard Co	W	247,842
Baton Rouge Area	LA	Subpart 2/Marginal	Ascension Par	W	76,627
Baton Rouge Area	LA	Subpart 2/Marginal	East Baton Rouge Par	W	412,852
Baton Rouge Area	LA	Subpart 2/Marginal	Iberville Par	W	33,320
Baton Rouge Area	LA	Subpart 2/Marginal	Livingston Par	W	91,814
Baton Rouge Area	LA	Subpart 2/Marginal	West Baton Rouge Par	W	21,601
Beaumont-Port Arthur Area	TX	Subpart 2/Marginal	Hardin Co	W	48,073
Beaumont-Port Arthur Area	TX	Subpart 2/Marginal	Jefferson Co	W	252,051
Beaumont-Port Arthur Area	TX	Subpart 2/Marginal	Orange Co	W	84,966
Benton Harbor Area	MI	Subpart 1	Berrien Co	W	162,453
Benzie County Area	MI	Subpart 1	Benzie Co	W	15,998
Berkeley and Jefferson Counties Area	WV	Subpart 1 - EAC	Berkeley Co	W	75,905
Berkeley and Jefferson Counties Area	WV	Subpart 1 - EAC	Jefferson Co	W	42,190
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Barnstable Co	W	222,230
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Bristol Co	W	534,678
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Dukes Co	W	14,987
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Essex Co	W	723,419
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Middlesex Co	W	1,465,396
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Nantucket Co	W	9,520
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Norfolk Co	W	650,308
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Plymouth Co	W	472,822
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Suffolk Co	W	689,807
Boston-Lawrence-Worcester (E. Mass) Area	MA	Subpart 2/Moderate	Worcester Co	W	750,963
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Hillsborough Co	P	336,518
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Merrimack Co	P	11,721
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Rockingham Co	P	266,340

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Boston-Manchester-Portsmouth (SE) Area	NH	Subpart 2/Moderate	Strafford Co	P	82,134
Buffalo-Niagara Falls Area	NY	Subpart 1	Erie Co	W	950,265
Buffalo-Niagara Falls Area	NY	Subpart 1	Niagara Co	W	219,846
Canton-Massillon Area	OH	Subpart 1	Stark Co	W	378,098
Cass County Area	MI	Subpart 2/Marginal	Cass Co	W	51,104
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Cabarrus Co	W	131,063
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Gaston Co	W	190,365
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Iredell Co	P	39,885
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Lincoln Co	W	63,780
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Mecklenburg Co	W	695,454
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Rowan Co	W	130,340
Charlotte-Gastonia-Rock Hill Area	NC	Subpart 2/Moderate	Union Co	W	123,677
Charlotte-Gastonia-Rock Hill Area	SC	Subpart 2/Moderate	York Co	P	102,000
Chattanooga Area	GA	Subpart 1 - EAC	Catoosa Co	W	53,282
Chattanooga Area	TN	Subpart 1 - EAC	Hamilton Co	W	307,896
Chattanooga Area	TN	Subpart 1 - EAC	Meigs Co	W	11,086
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Cook Co	W	5,376,741
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Du Page Co	W	904,161
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Grundy Co	P	6,309
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Kane Co	W	404,119
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Kendall Co	P	28,417
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Lake Co	W	644,356
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Mc Henry Co	W	260,077
Chicago-Gary-Lake County Area	IL	Subpart 2/Moderate	Will Co	W	502,266
Chicago-Gary-Lake County Area	IN	Subpart 2/Moderate	Lake Co	W	484,564
Chicago-Gary-Lake County Area	IN	Subpart 2/Moderate	Porter Co	W	146,798
Chico Area	CA	Subpart 1	Butte Co	W	203,171
Cincinnati-Hamilton Area	IN	Subpart 1	Dearborn Co	P	10,434
Cincinnati-Hamilton Area	KY	Subpart 1	Boone Co	W	85,991
Cincinnati-Hamilton Area	KY	Subpart 1	Campbell Co	W	88,616
Cincinnati-Hamilton Area	KY	Subpart 1	Kenton Co	W	151,464

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Cincinnati-Hamilton Area	OH	Subpart 1	Butler Co	W	332,807
Cincinnati-Hamilton Area	OH	Subpart 1	Clermont Co	W	177,977
Cincinnati-Hamilton Area	OH	Subpart 1	Clinton Co	W	40,543
Cincinnati-Hamilton Area	OH	Subpart 1	Hamilton Co	W	845,303
Cincinnati-Hamilton Area	OH	Subpart 1	Warren Co	W	158,383
Clearfield and Indiana Counties Area	PA	Subpart 1	Clearfield Co	W	83,382
Clearfield and Indiana Counties Area	PA	Subpart 1	Indiana Co	W	89,605
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Ashtabula Co	W	102,728
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Cuyahoga Co	W	1,393,978
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Geauga Co	W	90,895
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Lake Co	W	227,511
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Lorain Co	W	284,664
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Medina Co	W	151,095
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Portage Co	W	152,061
Cleveland-Akron-Lorain Area	OH	Subpart 2/Moderate	Summit Co	W	542,899
Columbia Area	SC	Subpart 1 - EAC	Lexington Co	P	181,265
Columbia Area	SC	Subpart 1 - EAC	Richland Co	P	313,253
Columbus Area	OH	Subpart 1	Delaware Co	W	109,989
Columbus Area	OH	Subpart 1	Fairfield Co	W	122,759
Columbus Area	OH	Subpart 1	Franklin Co	W	1,068,978
Columbus Area	OH	Subpart 1	Knox Co	W	54,500
Columbus Area	OH	Subpart 1	Licking Co	W	145,491
Columbus Area	OH	Subpart 1	Madison Co	W	40,213
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Collin Co	W	491,675
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Dallas Co	W	2,218,899
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Denton Co	W	432,976
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Ellis Co	W	111,360
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Johnson Co	W	126,811
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Kaufman Co	W	71,313
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Parker Co	W	88,495
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Rockwall Co	W	43,080
Dallas-Fort Worth Area	TX	Subpart 2/Moderate	Tarrant Co	W	1,446,219
Dayton-Springfield Area	OH	Subpart 1	Clark Co	W	144,742
Dayton-Springfield Area	OH	Subpart 1	Greene Co	W	147,886
Dayton-Springfield Area	OH	Subpart 1	Miami Co	W	98,868
Dayton-Springfield Area	OH	Subpart 1	Montgomery Co	W	559,062
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Adams Co	W	348,618
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Arapahoe Co	W	487,967
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Boulder Co	W	269,814
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Broomfield Co	W	38,272
Denver-Boulder-Greeley-Ft.	CO	Subpart 1 - EAC	Denver Co	W	554,636

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Collins-Love. Area					
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Douglas Co	W	175,766
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Jefferson Co	W	525,507
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Larimer Co	P	239,000
Denver-Boulder-Greeley-Ft. Collins-Love. Area	CO	Subpart 1 - EAC	Weld Co	P	172,000
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Lenawee Co	W	98,890
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Livingston Co	W	156,951
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Macomb Co	W	788,149
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Monroe Co	W	145,945
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Oakland Co	W	1,194,156
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	St Clair Co	W	164,235
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Washtenaw Co	W	322,895
Detroit-Ann Arbor Area	MI	Subpart 2/Marginal	Wayne Co	W	2,061,162
Door County Area	WI	Subpart 1	Door Co	W	27,961
Erie Area	PA	Subpart 1	Erie Co	W	280,843
Essex County (Whiteface Mtn.) Area	NY	Subpart 1	Essex Co	P	1,000
Fayetteville Area	NC	Subpart 1 - EAC	Cumberland Co	W	302,963
Flint Area	MI	Subpart 1	Genesee Co	W	436,141
Flint Area	MI	Subpart 1	Lapeer Co	W	87,904
Fort Wayne Area	IN	Subpart 1	Allen Co	W	331,849
Franklin County Area	PA	Subpart 1	Franklin Co	W	129,313
Frederick County Area	VA	Subpart 1 - EAC	Frederick Co	W	59,209
Frederick County Area	VA	Subpart 1 - EAC	Winchester	W	23,585
Grand Rapids Area	MI	Subpart 1	Kent Co	W	574,335
Grand Rapids Area	MI	Subpart 1	Ottawa Co	W	238,314
Greater Connecticut Area	CT	Subpart 2/Moderate	Hartford Co	W	857,183
Greater Connecticut Area	CT	Subpart 2/Moderate	Litchfield Co	W	182,193
Greater Connecticut Area	CT	Subpart 2/Moderate	New London Co	W	259,088
Greater Connecticut Area	CT	Subpart 2/Moderate	Tolland Co	W	136,364
Greater Connecticut Area	CT	Subpart 2/Moderate	Windham Co	W	109,091
Greene County Area	PA	Subpart 1	Greene Co	W	40,672
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Alamance Co	W	130,800
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Caswell Co	W	23,501
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Davidson Co	W	147,246
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Davie Co	W	34,835
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Forsyth Co	W	306,067
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Guilford Co	W	421,048

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Randolph Co	W	130,454
Greensboro-Winston-Salem-High Point Area	NC	Subpart 2/Marginal - EAC	Rockingham Co	W	91,928
Greenville-Spartanburg-Anderson Area	SC	Subpart 1 - EAC	Anderson Co	W	165,740
Greenville-Spartanburg-Anderson Area	SC	Subpart 1 - EAC	Greenville Co	W	379,616
Greenville-Spartanburg-Anderson Area	SC	Subpart 1 - EAC	Spartanburg Co	W	253,791
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Hancock Co	P	29,805
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Knox Co	P	33,563
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Lincoln Co	P	28,504
Hancock, Knox, Lincoln and Waldo Counties (Central Maine Coast) Area	ME	Subpart 1	Waldo Co	P	604
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Cumberland Co	W	213,674
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Dauphin Co	W	251,798
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Lebanon Co	W	120,327
Harrisburg-Lebanon-Carlisle Area	PA	Subpart 1	Perry Co	W	43,602
Haywood and Swain Counties (Great Smoky NP) Area	NC	Subpart 1	Haywood Co	P	28
Haywood and Swain Counties (Great Smoky NP) Area	NC	Subpart 1	Swain Co	P	260
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Alexander Co	W	33,603
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Burke Co	P	69,970
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Caldwell Co	P	64,254
Hickory-Morganton-Lenoir Area	NC	Subpart 1 - EAC	Catawba Co	W	141,685
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Brazoria Co	W	241,767
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Chambers Co	W	26,031
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Fort Bend Co	W	354,452
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Galveston Co	W	250,158
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Harris Co	W	3,400,578

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Liberty Co	W	70,154
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Montgomery Co	W	293,768
Houston-Galveston-Brazoria Area	TX	Subpart 2/Moderate	Waller Co	W	32,663
Huntington-Ashland Area	KY	Subpart 1	Boyd Co	W	49,752
Huron County Area	MI	Subpart 1	Huron Co	W	36,079
Imperial County Area	CA	Subpart 2/Marginal	Imperial Co	W	142,361
Indianapolis Area	IN	Subpart 1	Boone Co	W	46,107
Indianapolis Area	IN	Subpart 1	Hamilton Co	W	182,740
Indianapolis Area	IN	Subpart 1	Hancock Co	W	55,391
Indianapolis Area	IN	Subpart 1	Hendricks Co	W	104,093
Indianapolis Area	IN	Subpart 1	Johnson Co	W	115,209
Indianapolis Area	IN	Subpart 1	Madison Co	W	133,358
Indianapolis Area	IN	Subpart 1	Marion Co	W	860,454
Indianapolis Area	IN	Subpart 1	Morgan Co	W	66,689
Indianapolis Area	IN	Subpart 1	Shelby Co	W	43,445
Jamestown Area	NY	Subpart 1	Chautauqua Co	W	139,750
Jefferson County Area	NY	Subpart 2/Moderate	Jefferson Co	W	111,738
Johnson City-Kingsport-Bristol Area	TN	Subpart 1 - EAC	Hawkins Co	W	53,563
Johnson City-Kingsport-Bristol Area	TN	Subpart 1 - EAC	Sullivan Co	W	153,048
Johnstown Area	PA	Subpart 1	Cambria Co	W	152,598
Kalamazoo-Battle Creek Area	MI	Subpart 1	Calhoun Co	W	137,985
Kalamazoo-Battle Creek Area	MI	Subpart 1	Kalamazoo Co	W	238,603
Kalamazoo-Battle Creek Area	MI	Subpart 1	Van Buren Co	W	76,263
Kent and Queen Anne's Counties Area	MD	Subpart 2/Marginal	Kent Co	W	19,197
Kent and Queen Anne's Counties Area	MD	Subpart 2/Marginal	Queen Annes Co	W	40,563
Kern County (Eastern Kern) Area	CA	Subpart 1	Kern Co	P	99,251
Kewaunee County Area	WI	Subpart 1	Kewaunee Co	W	20,187
Knoxville Area	TN	Subpart 1	Anderson Co	W	71,330
Knoxville Area	TN	Subpart 1	Blount Co	W	105,823
Knoxville Area	TN	Subpart 1	Cocke Co	P	20
Knoxville Area	TN	Subpart 1	Jefferson Co	W	44,294
Knoxville Area	TN	Subpart 1	Knox Co	W	382,032
Knoxville Area	TN	Subpart 1	Loudon Co	W	39,086
Knoxville Area	TN	Subpart 1	Sevier Co	W	71,170
La Porte County Area	IN	Subpart 2/Marginal	La Porte Co	W	110,106
Lancaster Area	PA	Subpart 2/Marginal	Lancaster Co	W	470,658
Lansing-East Lansing Area	MI	Subpart 1	Clinton Co	W	64,753
Lansing-East Lansing Area	MI	Subpart 1	Eaton Co	W	103,655
Lansing-East Lansing Area	MI	Subpart 1	Ingham Co	W	279,320

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Las Vegas Area	NV	Subpart 1	Clark Co	P	1,348,864
Lima Area	OH	Subpart 1	Allen Co	W	108,473
Los Angeles and San Bernardino Counties (W Mojave Desert) Area	CA	Subpart 2/Moderate	Los Angeles Co	P	297,058
Los Angeles and San Bernardino Counties (W Mojave Desert) Area	CA	Subpart 2/Moderate	San Bernardino Co	P	359,350
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	Los Angeles Co	P	9,222,280
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	Orange Co	W	2,846,289
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	Riverside Co	P	1,194,859
Los Angeles-South Coast Air Basin Area	CA	Subpart 2/Severe 17	San Bernardino Co	P	1,330,159
Louisville Area	IN	Subpart 1	Clark Co	W	96,472
Louisville Area	IN	Subpart 1	Floyd Co	W	70,823
Louisville Area	KY	Subpart 1	Bullitt Co	W	61,236
Louisville Area	KY	Subpart 1	Jefferson Co	W	693,604
Louisville Area	KY	Subpart 1	Oldham Co	W	46,178
Macon Area	GA	Subpart 1	Bibb Co	W	153,887
Macon Area	GA	Subpart 1	Monroe Co	P	50
Manitowoc County Area	WI	Subpart 1	Manitowoc Co	W	82,887
Mariposa and Tuolumne Counties (Southern Mountain Counties) Area	CA	Subpart 1	Mariposa Co	W	17,130
Mariposa and Tuolumne Counties (Southern Mountain Counties) Area	CA	Subpart 1	Tuolumne Co	W	54,501
Mason County Area	MI	Subpart 1	Mason Co	W	28,274
Memphis Area	AR	Subpart 2/Marginal	Crittenden Co	W	50,866
Memphis Area	TN	Subpart 2/Marginal	Shelby Co	W	897,472
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Kenosha Co	W	149,577
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Milwaukee Co	W	940,164
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Ozaukee Co	W	82,317
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Racine Co	W	188,831
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Washington Co	W	117,493
Milwaukee-Racine Area	WI	Subpart 2/Moderate	Waukesha Co	W	360,767
Murray County (Chattahoochee Nat Forest) Area	GA	Subpart 1	Murray Co	P	1,000
Muskegon Area	MI	Subpart 2/Marginal	Muskegon Co	W	170,200
Nashville Area	TN	Subpart 1 - EAC	Davidson Co	W	569,891
Nashville Area	TN	Subpart 1 - EAC	Rutherford Co	W	182,023
Nashville Area	TN	Subpart 1 - EAC	Sumner Co	W	130,449
Nashville Area	TN	Subpart 1 - EAC	Williamson Co	W	126,638
Nashville Area	TN	Subpart 1 - EAC	Wilson Co	W	88,809

8-hour Ozone Nonattainment	State	Classification^{a,b}	County Name	Whole /Part	2000 Cty Pop
Nevada County (Western part) Area	CA	Subpart 1	Nevada Co	P	77,735
New York-N. New Jersey-Long Island Area	CT	Subpart 2/Moderate	Fairfield Co	W	882,567
New York-N. New Jersey-Long Island Area	CT	Subpart 2/Moderate	Middlesex Co	W	155,071
New York-N. New Jersey-Long Island Area	CT	Subpart 2/Moderate	New Haven Co	W	824,008
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Bergen Co	W	884,118
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Essex Co	W	793,633
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Hudson Co	W	608,975
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Hunterdon Co	W	121,989
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Middlesex Co	W	750,162
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Monmouth Co	W	615,301
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Morris Co	W	470,212
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Passaic Co	W	489,049
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Somerset Co	W	297,490
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Sussex Co	W	144,166
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Union Co	W	522,541
New York-N. New Jersey-Long Island Area	NJ	Subpart 2/Moderate	Warren Co	W	102,437
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Bronx Co	W	1,332,650
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Kings Co	W	2,465,326
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Nassau Co	W	1,334,544
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	New York Co	W	1,537,195
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Queens Co	W	2,229,379
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Richmond Co	W	443,728
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Rockland Co	W	286,753
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Suffolk Co	W	1,419,369
New York-N. New Jersey-Long Island Area	NY	Subpart 2/Moderate	Westchester Co	W	923,459
Norfolk-Virginia Beach-Newport News (Hampton	VA	Subpart 2/Marginal	Chesapeake	W	199,184

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Roads) Area					
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Gloucester Co	W	34,780
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Hampton	W	146,437
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Isle Of Wight Co	W	29,728
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	James City Co	W	48,102
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Newport News	W	180,150
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Norfolk	W	234,403
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Poquoson	W	11,566
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Portsmouth	W	100,565
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Suffolk	W	63,677
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Virginia Beach	W	425,257
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	Williamsburg	W	11,998
Norfolk-Virginia Beach-Newport News (Hampton Roads) Area	VA	Subpart 2/Marginal	York Co	W	56,297
Parkersburg-Marietta Area	OH	Subpart 1	Washington Co	W	63,251
Parkersburg-Marietta Area	WV	Subpart 1	Wood Co	W	87,986
Philadelphia-Wilmington-Atlantic City Area	DE	Subpart 2/Moderate	Kent Co	W	126,697
Philadelphia-Wilmington-Atlantic City Area	DE	Subpart 2/Moderate	New Castle Co	W	500,265
Philadelphia-Wilmington-Atlantic City Area	DE	Subpart 2/Moderate	Sussex Co	W	156,638
Philadelphia-Wilmington-Atlantic City Area	MD	Subpart 2/Moderate	Cecil Co	W	85,951
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Atlantic Co	W	252,552
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Burlington Co	W	423,394

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Camden Co	W	508,932
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Cape May Co	W	102,326
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Cumberland Co	W	146,438
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Gloucester Co	W	254,673
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Mercer Co	W	350,761
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Ocean Co	W	510,916
Philadelphia-Wilmington-Atlantic City Area	NJ	Subpart 2/Moderate	Salem Co	W	64,285
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Bucks Co	W	597,635
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Chester Co	W	433,501
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Delaware Co	W	550,864
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Montgomery Co	W	750,097
Philadelphia-Wilmington-Atlantic City Area	PA	Subpart 2/Moderate	Philadelphia Co	W	1,517,550
Phoenix-Mesa Area	AZ	Subpart 1	Maricopa Co	P	3,054,504
Phoenix-Mesa Area	AZ	Subpart 1	Pinal Co	P	31,541
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Allegheny Co	W	1,281,666
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Armstrong Co	W	72,392
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Beaver Co	W	181,412
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Butler Co	W	174,083
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Fayette Co	W	148,644
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Washington Co	W	202,897
Pittsburgh-Beaver Valley Area	PA	Subpart 1	Westmoreland Co	W	369,993
Portland Area	ME	Subpart 2/Marginal	Androscoggin Co	P	3,390
Portland Area	ME	Subpart 2/Marginal	Cumberland Co	P	252,907
Portland Area	ME	Subpart 2/Marginal	Sagadahoc Co	W	35,214
Portland Area	ME	Subpart 2/Marginal	York Co	P	164,997
Poughkeepsie Area	NY	Subpart 2/Moderate	Dutchess Co	W	280,150
Poughkeepsie Area	NY	Subpart 2/Moderate	Orange Co	W	341,367
Poughkeepsie Area	NY	Subpart 2/Moderate	Putnam Co	W	95,745
Providence (all of RI) Area	RI	Subpart 2/Moderate	Bristol Co	W	50,648
Providence (all of RI) Area	RI	Subpart 2/Moderate	Kent Co	W	167,090
Providence (all of RI) Area	RI	Subpart 2/Moderate	Newport Co	W	85,433

8-hour Ozone Nonattainment	**State**	**Classification[a,b]**	**County Name**	**Whole /Part**	**2000 Cty Pop**
Providence (all of RI) Area	RI	Subpart 2/Moderate	Providence Co	W	621,602
Providence (all of RI) Area	RI	Subpart 2/Moderate	Washington Co	W	123,546
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Chatham Co	P	21,320
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Durham Co	W	223,314
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Franklin Co	W	47,260
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Granville Co	W	48,498
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Johnston Co	W	121,965
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Orange Co	W	118,227
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Person Co	W	35,623
Raleigh-Durham-Chapel Hill Area	NC	Subpart 1	Wake Co	W	627,846
Reading Area	PA	Subpart 1	Berks Co	W	373,638
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Charles City Co	W	6,926
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Chesterfield Co	W	259,903
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Colonial Heights	W	16,897
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Hanover Co	W	86,320
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Henrico Co	W	262,300
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Hopewell	W	22,354
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Petersburg	W	33,740
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Prince George Co	W	33,047
Richmond-Petersburg Area	VA	Subpart 2/Marginal	Richmond	W	197,790
Riverside County (Coachella Valley) Area	CA	Subpart 2/Serious	Riverside Co	P	324,750
Roanoke Area	VA	Subpart 1 - EAC	Botetourt Co	W	30,496
Roanoke Area	VA	Subpart 1 - EAC	Roanoke	W	94,911
Roanoke Area	VA	Subpart 1 - EAC	Roanoke Co	W	85,778
Roanoke Area	VA	Subpart 1 - EAC	Salem	W	24,747
Rochester Area	NY	Subpart 1	Genesee Co	W	60,370
Rochester Area	NY	Subpart 1	Livingston Co	W	64,328
Rochester Area	NY	Subpart 1	Monroe Co	W	735,343
Rochester Area	NY	Subpart 1	Ontario Co	W	100,224
Rochester Area	NY	Subpart 1	Orleans Co	W	44,171
Rochester Area	NY	Subpart 1	Wayne Co	W	93,765
Rocky Mount Area	NC	Subpart 1	Edgecombe Co	W	55,606
Rocky Mount Area	NC	Subpart 1	Nash Co	W	87,420
Sacramento Metro Area	CA	Subpart 2/Serious	El Dorado Co	P	124,164
Sacramento Metro Area	CA	Subpart 2/Serious	Placer Co	P	239,978
Sacramento Metro Area	CA	Subpart 2/Serious	Sacramento Co	W	1,223,499
Sacramento Metro Area	CA	Subpart 2/Serious	Solano Co	P	197,034
Sacramento Metro Area	CA	Subpart 2/Serious	Sutter Co	P	25,013
Sacramento Metro Area	CA	Subpart 2/Serious	Yolo Co	W	168,660

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
San Antonio Area	TX	Subpart 1 - EAC	Bexar Co	W	1,392,931
San Antonio Area	TX	Subpart 1 - EAC	Comal Co	W	78,021
San Antonio Area	TX	Subpart 1 - EAC	Guadalupe Co	W	89,023
San Diego Area	CA	Subpart 1	San Diego Co	P	2,813,431
San Francisco Bay Area	CA	Subpart 2/Marginal	Alameda Co	W	1,443,741
San Francisco Bay Area	CA	Subpart 2/Marginal	Contra Costa Co	W	948,816
San Francisco Bay Area	CA	Subpart 2/Marginal	Marin Co	W	247,289
San Francisco Bay Area	CA	Subpart 2/Marginal	Napa Co	W	124,279
San Francisco Bay Area	CA	Subpart 2/Marginal	San Francisco Co	W	776,733
San Francisco Bay Area	CA	Subpart 2/Marginal	San Mateo Co	W	707,161
San Francisco Bay Area	CA	Subpart 2/Marginal	Santa Clara Co	W	1,682,585
San Francisco Bay Area	CA	Subpart 2/Marginal	Solano Co	P	197,508
San Francisco Bay Area	CA	Subpart 2/Marginal	Sonoma Co	P	413,716
San Joaquin Valley Area	CA	Subpart 2/Serious	Fresno Co	W	799,407
San Joaquin Valley Area	CA	Subpart 2/Serious	Kern Co	P	550,220
San Joaquin Valley Area	CA	Subpart 2/Serious	Kings Co	W	129,461
San Joaquin Valley Area	CA	Subpart 2/Serious	Madera Co	W	123,109
San Joaquin Valley Area	CA	Subpart 2/Serious	Merced Co	W	210,554
San Joaquin Valley Area	CA	Subpart 2/Serious	San Joaquin Co	W	563,598
San Joaquin Valley Area	CA	Subpart 2/Serious	Stanislaus Co	W	446,997
San Joaquin Valley Area	CA	Subpart 2/Serious	Tulare Co	W	368,021
Scranton-Wilkes-Barre Area	PA	Subpart 1	Lackawanna Co	W	213,295
Scranton-Wilkes-Barre Area	PA	Subpart 1	Luzerne Co	W	319,250
Scranton-Wilkes-Barre Area	PA	Subpart 1	Monroe Co	W	138,687
Scranton-Wilkes-Barre Area	PA	Subpart 1	Wyoming Co	W	28,080
Sheboygan Area	WI	Subpart 2/Moderate	Sheboygan Co	W	112,646
South Bend-Elkhart Area	IN	Subpart 1	Elkhart Co	W	182,791
South Bend-Elkhart Area	IN	Subpart 1	St Joseph Co	W	265,559
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Berkshire Co	W	134,953
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Franklin Co	W	71,535
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Hampden Co	W	456,228
Springfield (W. Mass) Area	MA	Subpart 2/Moderate	Hampshire Co	W	152,251
St. Louis Area	IL	Subpart 2/Moderate	Jersey Co	W	21,668
St. Louis Area	IL	Subpart 2/Moderate	Madison Co	W	258,941
St. Louis Area	IL	Subpart 2/Moderate	Monroe Co	W	27,619
St. Louis Area	IL	Subpart 2/Moderate	St Clair Co	W	256,082
St. Louis Area	MO	Subpart 2/Moderate	Franklin Co	W	93,807
St. Louis Area	MO	Subpart 2/Moderate	Jefferson Co	W	198,099
St. Louis Area	MO	Subpart 2/Moderate	St Charles Co	W	283,883
St. Louis Area	MO	Subpart 2/Moderate	St Louis	W	348,189
St. Louis Area	MO	Subpart 2/Moderate	St Louis Co	W	1,016,315
State College Area	PA	Subpart 1	Centre Co	W	135,758
Steubenville-Weirton Area	OH	Subpart 1	Jefferson Co	W	73,894
Steubenville-Weirton Area	WV	Subpart 1	Brooke Co	W	25,447
Steubenville-Weirton Area	WV	Subpart 1	Hancock Co	W	32,667

8-hour Ozone Nonattainment	State	Classification[a,b]	County Name	Whole /Part	2000 Cty Pop
Sutter County (part) (Sutter Buttes) Area	CA	Subpart 1	Sutter Co	P	1
Tioga County Area	PA	Subpart 1	Tioga Co	W	41,373
Toledo Area	OH	Subpart 1	Lucas Co	W	455,054
Toledo Area	OH	Subpart 1	Wood Co	W	121,065
Ventura County (part) Area	CA	Subpart 2/Moderate	Ventura Co	P	753,197
Washington Area	DC	Subpart 2/Moderate	Entire District	W	572,059
Washington Area	MD	Subpart 2/Moderate	Calvert Co	W	74,563
Washington Area	MD	Subpart 2/Moderate	Charles Co	W	120,546
Washington Area	MD	Subpart 2/Moderate	Frederick Co	W	195,277
Washington Area	MD	Subpart 2/Moderate	Montgomery Co	W	873,341
Washington Area	MD	Subpart 2/Moderate	Prince George's Co	W	801,515
Washington Area	VA	Subpart 2/Moderate	Alexandria	W	128,283
Washington Area	VA	Subpart 2/Moderate	Arlington Co	W	189,453
Washington Area	VA	Subpart 2/Moderate	Fairfax	W	21,498
Washington Area	VA	Subpart 2/Moderate	Fairfax Co	W	969,749
Washington Area	VA	Subpart 2/Moderate	Falls Church	W	10,377
Washington Area	VA	Subpart 2/Moderate	Loudoun Co	W	169,599
Washington Area	VA	Subpart 2/Moderate	Manassas	W	35,135
Washington Area	VA	Subpart 2/Moderate	Manassas Park	W	10,290
Washington Area	VA	Subpart 2/Moderate	Prince William Co	W	280,813
Washington County (Hagerstown) Area	MD	Subpart 1 - EAC	Washington Co	W	131,923
Wheeling Area	OH	Subpart 1	Belmont Co	W	70,226
Wheeling Area	WV	Subpart 1	Marshall Co	W	35,519
Wheeling Area	WV	Subpart 1	Ohio Co	W	47,427
York Area	PA	Subpart 1	Adams Co	W	91,292
York Area	PA	Subpart 1	York Co	W	381,751
Youngstown-Warren-Sharon Area	OH	Subpart 1	Columbiana Co	W	112,075
Youngstown-Warren-Sharon Area	OH	Subpart 1	Mahoning Co	W	257,555
Youngstown-Warren-Sharon Area	OH	Subpart 1	Trumbull Co	W	225,116
Youngstown-Warren-Sharon Area	PA	Subpart 1	Mercer Co	W	120,293

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[21] Currently, two established receptor models are widely used for source apportionment studies: the Chemical Mass Balance (CMB) model and Positive Matrix Factorization (PMF). The CMB receptor model relies on measured source profiles as well as ambient species measurements to produce a source contribution estimate at the receptor location, while the

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PMF technique decomposes the ambient measurement data matrix into source profiles and contributions by utilizing the underlying relationship (i.e., correlations) between the individually measured species.

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Emission Inventory

This chapter presents our analysis of the emission impact of the proposed rule for the three source categories affected: commercial marine diesel engines, recreational marine diesel engines, and locomotives. The proposed control requirements include NO_x and PM[a] emission standards for Category 1 and Category 2 commercial marine diesel engines (both above and below 37 kilowatts [kW]). New NO_x and PM emission standards would also apply to all recreational marine diesel engines and locomotives. There are no new standards for HC or CO; however, the PM standards are also expected to decrease HC emissions.

Section 3.1 describes the methodology and presents the resulting baseline and controlled inventories for commercial marine diesel engines, including the projected emission reductions from the proposed rule. Sections 3.2 and 3.3 present similar information for recreational marine diesel engines and locomotives, respectively. The baseline inventories represent current and future emissions with only the existing standards. The controlled inventories incorporate the new standards in the proposed rule. Section 3.4 follows with the total projected emission reductions from all three affected source categories. Section 3.5 and section 3.6 then describe the contribution of these source categories to national and selected local inventories, respectively. Section 3.7 concludes the chapter by describing the changes in the inputs and resulting emission inventories between the baseline and control scenarios used for the air quality modeling and the updated baseline and control scenarios in this proposed rule.

The inventory estimates reported in this chapter are for the 50-state geographic area. Inventories are presented for the following pollutants: particulate matter ($PM_{2.5}$ and PM_{10}), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOC), carbon monoxide (CO), and mobile source air toxics. The specific air toxics are benzene, formaldehyde, acetaldehyde, 1,3-butadiene, acrolein, napthalene, and 15 other compounds grouped together as polycyclic organic matter (POM). The PM inventories include directly emitted PM only, although secondary sulfates are taken into account in the air quality modeling.

3.1 Commercial Marine Diesel Engines

This section describes the methodology and presents the resulting baseline and controlled inventories for commercial marine diesel engines, including the projected emission reductions from the proposed rule. Separate inventories were developed for the following commercial marine diesel engine categories: Category 1 commercial propulsion, Category 1 marine auxiliary, Category 2 commercial propulsion, less than (<) 37kW commercial propulsion, and <37kW marine auxiliary. Category 1 and 2 only include engines greater than or equal to (≥) 37kW, so it was necessary to include separate categories for those

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[a] PM in this document refers to PM_{10}, which are particles less than 10 microns in diameter.

engines less than 37kW. Note that the auxiliary categories include engines used on either commercial or recreational vessels; however, given the expected small number of recreational auxiliary engines in comparison to commercial auxiliary engines, and our inability to separate the auxiliary categories by end use, the auxiliary categories have been included in the broader commercial marine category. Category 2 marine auxiliary engines are not included here, since they are used on Category 3 ocean-going vessels that are primarily foreign-flagged and not subject to U.S. regulations. Emissions from Category 2 auxiliary engines are therefore part of the Category 3 inventories.

3.1.1 General Methodology

The general methodology for calculating commercial marine diesel engine inventories for HC, CO, NO_x, and PM is first described. This is followed by the methodologies used to calculate fuel consumption, SO_2, VOC, $PM_{2.5}$, and air toxic inventories.

Commercial marine diesel engine inventories for HC, CO, NO_x, and PM are estimated using the equation:

Equation 1 $$I = N*P*L*A*EF$$

where each term is defined as follows:

I = the emission inventory (gram/year)
N = engine population (units)
P = average rated power (kW)
L = load factor (average fraction of rated power used during operation; unitless)
A = engine activity (operating hours/year)
EF = emission factor (gram/kW-hr)

Emissions are then converted and reported as short tons/year.

The average rated power, load factor, and activity inputs remain constant in any given simulation year. However, populations and emission factors vary by year and age. Populations for a given base calendar year are first calculated, along with the corresponding age distribution, and then projected from that base year into the future. For most of the commercial marine diesel categories, the base year is 2002. The pollutant emission factors vary by age to account for the current and proposed regulations, as well as emissions deterioration. PM emission factors also have an additional adjustment to account for the in-use fuel sulfur level, which is described in more detail below.

Three variables are used to project emissions over time: the annual population growth rate, the engine median life/scrappage, and the relative deterioration rate. Collectively, these variables represent population growth, changes in the population age distribution, and emission deterioration.

Annual Population Growth Rate (percent/year). The population growth rate represents the percentage increase in the total calendar year engine population from year (n) to year (n+1). It is a compound growth rate. These growth rates vary by category.

Engine Median Life (years) and Scrappage. The engine median life defines the length of time engines remain in service. Engines persist in the population over two median lives; during the first median life, 50 percent of the engines are scrapped, and over the second, the remaining 50 percent of the engines are scrapped. Engine median lives also vary by category. The age distribution is defined by the median life and the scrappage algorithm. For commercial marine diesel engines, the scrappage algorithm in the NONROAD model was used for all categories.[1]

Relative Deterioration Rate (percent increase in emission factor/percent median life expended). A deterioration factor can be applied to the emission factor to account for in-use deterioration. The deterioration factor varies by age and is calculated as:

Equation 2 $$DF = 1 + A*(age/ML)$$

where each term is defined as follows:
DF = the deterioration factor for a given pollutant at a given age
A = the relative deterioration rate for a given pollutant (percent increase in emission factor/percent useful life expended)
age = the age of a specific model year group of engines in the simulation year (years)
ML = the median life of the given model year cohort (years)

A given model year cohort is represented as a fraction of the entire population. The deterioration factor adjusts the emission factor for engines in a given model year cohort in relation to the proportion of median life expended. Deterioration is linear over one median life. Following the first median life, the deteriorated emission factor is held constant over the remaining life for engines in the cohort. This is consistent with the diesel deterioration applied in the NONROAD model.[2]

Sulfur Adjustment for PM Emissions. For Tier 2 and prior engines, a sulfate adjustment is added to the PM emissions to account for differences in fuel sulfur content between the certification fuel and the episodic (calendar year) fuel, using the following equation:

Equation 3 $$S_{PM\ adj} = FC * 7.1 * 0.02247 * 224/32 * (soxdsl - soxbas) * 1/2000$$

where each term is defined as follows:
$S_{PM\ adj}$ = PM sulfate adjustment (tons)
FC = fuel consumption (gallons)
7.1 = fuel density (lb/gal)
0.02247 = fraction of fuel sulfur converted to sulfate
224/32 = grams PM sulfate/grams PM sulfur
soxdsl = episodic fuel sulfur weight fraction (varies by calendar year)
soxbas = certification fuel sulfur weight fraction
2000 = conversion from lb to ton

For Tier 3 and later engines, no sulfur adjustment is applied. These engines will be certified to a fuel sulfur level at or lower than the episodic fuel sulfur levels expected when these engines are introduced.

Estimation of fuel consumption. Annual fuel consumption is estimated using the following equation:

Equation 4 $$FC = (BSFC * N * P * L * A)/(7.1 * 454)$$

where each term is defined as follows:
FC = fuel consumption (gallons)
BSFC = brake specific fuel consumption (g/kW-hr)
N = engine population (units)
P = average rated power (kW)
L = load factor (average fraction of rated power used during operation; unitless)
A = engine activity (operating hours/year)
7.1 = fuel density (lb/gal)
454 = conversion from lb to g

Estimation of SO_2 emissions. Annual SO_2 inventories are estimated using the following equation:

Equation 5 $$SO_2 = FC * 7.1 * (1-0.02247) * 64/32 * soxdsl * 1/2000$$

where each term is defined as follows:
SO_2 = sulfur dioxide inventory (tons)
FC = fuel consumption (gallons)
7.1 = fuel density (lb/gal)
(1-0.02247) = fraction of fuel sulfur converted to SO_2
64/32 = grams SO_2/grams sulfur
soxdsl = episodic fuel sulfur weight fraction (varies by calendar year)
2000 = conversion from lb to ton

The calendar year fuel sulfur levels (soxdsl) were taken from the Clean Air Nonroad Diesel Rule.[4]

Estimation of VOC and $PM_{2.5}$ emissions. To estimate VOC emissions, an adjustment factor of 1.053 is applied to the HC output. Similarly, to estimate $PM_{2.5}$ emissions, an adjustment factor of 0.97 is applied to the PM_{10} output. These adjustment factors are consistent with those used in the NONROAD model[3,2] and the Clean Air Nonroad Diesel Rule.[4]

Estimation of air toxic emissions. The air toxic baseline emission inventories for this proposal are based on information developed for EPA's Mobile Source Air Toxics (MSAT) final rulemaking.[5] That rule calculated air toxic emission inventories for all nonroad engines. The gaseous air toxics are correlated to VOC emissions, while POM is correlated to PM_{10} emissions. To calculate the air toxics emission inventories and reductions for this proposal, the percent reductions in VOC and PM_{10} emissions will be applied to the baseline gaseous and POM air toxic inventories, respectively.

3.1.2 Baseline (Pre-Control) Inventory Development

This section describes the inputs and provides the resulting baseline inventories for commercial marine engines.

3.1.2.1 Category 1 Propulsion

The inventory inputs of base year population, average power, load factor, and activity for Category 1 commercial propulsion engines are given in Table 0-1 and Table 0-2. These inventory inputs are used to develop both baseline and control inventories. As a result, there are displacement, power density, and kilowatt subcategories, which are required to model both the current and proposed standards in this rule.

The current emission standards vary only by displacement (disp) category, which is expressed as liters per cylinder (L/cyl). There are four displacement categories for Category 1 engines: 1) less than 0.9 L/cyl (and power greater than or equal to 37kW), 2) greater than or equal to 0.9 L/cyl and less than 1.2 L/cyl, 3) greater than or equal to 1.2 L/cyl and less than 2.5 L/cyl, and 4) greater than or equal to 2.5 L/cyl and less than 5 L/cyl. For simplification, these will be referred to as 1) disp <0.9, 2) 0.9≤ disp <1.2, 3) 1.2≤ disp <2.5, and 4) 2.5≤ disp <5.

In order to model the proposed Tier 3 standards, the 2.5≤ disp <5 category is further broken out into 2.5≤ disp <3.5 and 3.5≤ disp <5 categories. The Tier 3 standards also have cut points at 75kW and 3700kW, so it was necessary to break out the disp<0.9 category into 37<kW≤75 and >75kW categories. Since there are no Category 1 engines greater than 3700kW, this cut point was not necessary to include. Finally, there are different Tier 3 standards for standard power density and high power density engines. Standard power density engines are less than 35 kW per liter (kW/L), and the high power density engines are greater than or equal to 35 kW/L. The inputs for the standard power density engines are given in Table 0-1 and the inputs for the high power density engines in Table 0-2.

The proposed Tier 4 standards that apply to Category 1 engines vary by the following kW categories: <600kW, 600≤kW<1000, 1000≤kW<1400, 1400≤kW<3700, and ≥3700kW. As a result, these power categories were also added, with the exception of the ≥3700kW category, since there are no Category 1 engines in this power range.

The base year populations by displacement category are generated using historical sales estimates in conjunction with the scrappage algorithm described above. Other inventory inputs that affect scrappage are load factor, activity, and median life. The historical sales estimates for calendar years 1973-2002 were obtained from Power Systems Research (PSR). These populations by displacement category were further broken out into power density and kilowatt categories using the 2002 population and engine data from PSR.

The average power estimates were population-weighted, using the 2002 engine and population data from PSR. The load factor and activity estimates were 0.45 and 943 hours per year, respectively for engines <560 kW (750 hp). These are the estimates for commercial marine propulsion engines provided by PSR. For engines >560 kW, the load factor and activity estimates used were 0.79 and 4,503 hours per year. These latter estimates were taken from the 1999 Marine Diesel FRM.[6] Higher load factors and activities were assigned to these larger engines based on information provided by the manufacturers for the previous rule, and supported by more recent discussions with the American Waterways Operators about how these larger engines typically operate.[7] This power break point is not related to the kW categories in the proposed standards.

Load factors for each subcategory were developed by first identifying the engines in the PSR population dataset corresponding to each subcategory. Load factors for each engine in a subcategory were assigned based on the criteria above. An average load factor for each subcategory was then obtained by weighting the individual engine load factors by population and power. A similar approach was followed to obtain activity estimates for each subcategory, with the exception that the weightings were population, power, and load factor. The average power, load factors and activities needed to be estimated using these weightings to ensure that the total inventory from this source category is correctly calculated.

The median life for all C1 propulsion engines used is 13 years, which is the estimate provided by PSR. The annual population growth rate is 1.009, which is the estimate from the Energy and Information Administration (EIA) for domestic shipping.[8]

Table 0-1 Inventory Inputs for C1 Propulsion Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 W/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	1,665	43	0.45	943	0				1,665
DISP<0.9 AND >75KW	1,102	154	0.45	943	0				1,102
0.9<=DISP<1.2	19,255	128	0.45	943	0				19,255
1.2<=DISP<2.5	23,561	294	0.51	1,905	795	781	0.79	4,503	24,356
2.5<=DISP<3.5	5,898	397	0.45	943	675	832	0.79	4,503	6,573
3.5<=DISP<5.0	205	404	0.45	943	308	748	0.79	4,503	513
TOTAL	51,687				1,777				53,464

DISPLACEMENT CATEGORY	<35 KW/L								TOTAL POPULATION
	1000<KW≤1400KW				>1400KW*				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	1,013	1,065	0.79	4,503	0				1,013
2.5<=DISP<3.5	186	1,194	0.79	4,503	0				186
3.5<=DISP<5.0	212	1,119	0.79	4,503	1,264	1,492	0.79	4,503	1,476
TOTAL	1,411				1,264				2,675

Grand Total 53,098 3,041 56,139

* No populations ≥3700KW

Table 0-2 Inventory Inputs for C1 Propulsion High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	3,151	165	0.45	943	0				3,151
0.9<=DISP<1.2	21	313	0.45	943	0				21
1.2<=DISP<2.5	1,338	341	0.45	943	102	678	0.79	4,503	1,440
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	0				0				0
TOTAL	4,510				102				4,612

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	1000<KW≤1400KW				>1400KW*				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	0				0				0
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	214	1,176	0.79	4,503	361	1,765	0.79	4,503	575
TOTAL	214				361				575

Grand Total 4,724 463 5,187

* No populations ≥3700KW

The baseline emission factors are given in Table 0-3 and Table 0-4. The emission factors are provided for three technology types: Base, Tier 1, and Tier 2. The base technology type includes all pre-control engines. Tier 1 refers to the first round of existing standards for NO_x only that begin in 2000. Tier 2 refers to the second round of existing standards for HC+NO_x and PM that began in 2004 to 2007, depending on the displacement category.

Table 0-3 Baseline PM_{10} and NO_x Emission Factors for C1 Propulsion Engines*

DISPLACEMENT CATEGORY	PM_{10} G/KW-HR			NO_X G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.54	0.54	0.23	10	9.8	5.7
0.9<=DISP<1.2	0.47	0.47	0.12	10	9.8	6.1
1.2<=DISP<2.5	0.34	0.34	0.13	10	9.8	6.0
2.5<=DISP<3.5	0.30	0.30	0.13	10	9.1	6.0
3.5<=DISP<5.0	0.30	0.30	0.13	11	9.2	6.0

* Deterioration is applied to the PM emission factors (EFs); see text for details. The NO_x EFs are not subject to deterioration.

Table 0-4 Baseline HC and CO Emission Factors for C1 Propulsion Engines*

DISPLACEMENT CATEGORY	HC G/KW-HR			CO G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.41	0.41	0.41	1.6	1.6	1.6
0.9<=DISP<1.2	0.32	0.32	0.32	1.6	1.6	0.9
1.2<=DISP<2.5	0.27	0.27	0.19	1.6	1.6	1.1
2.5<=DISP<3.5	0.27	0.27	0.19	1.6	1.6	1.1
3.5<=DISP<5.0	0.27	0.27	0.19	1.8	1.8	1.1

* The HC and CO emission factors (EFs) are not subject to deterioration.

The base emission factors were taken from the 1999 Marine Diesel rulemaking, and are based on emission data for uncontrolled engines.[6] For Tier 1, the NO_x emission factors were estimated using 2006 certification data. The certification data for engines using the E3 cycle[b] were sales-weighted to obtain Tier 1 NO_x emission factors for each displacement category. Since the Tier 1 standards only affect NO_x, the Tier 1 emission factors for the other pollutants are equal to the base

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[b] The E3 duty cycle is designated for propulsion marine diesel engines.

emission factors. For Tier 2, the same 2006 certification data were used to estimate PM, NO_x, and HC emission factors.

For C1 engines, PM is the only pollutant for which deterioration factors are applied. The relative deterioration rate (A) is 0.473, which is used for both pre-control and all regulatory tiers. As a result, the maximum PM deterioration factor is 1.473. This is consistent with the diesel deterioration assumed in the NONROAD model.[2]

The certification fuel sulfur levels, which are used to estimate the PM sulfate adjustments, are 3300ppm for the Base (pre-control) technology type, and 350ppm for Tier 1 and Tier 2. The Base level was taken from the NONROAD model.[2] The Tier 1 and Tier 2 levels were estimated from reviewing the marine certification data and fuel requirements.

For calculating fuel consumption, estimates of brake specific fuel consumption (BSFC) are also required. For this analysis, a value of 213 g/kW-hr was used. This value is consistent with published estimates of BSFC and those for heavy-duty diesel engines.[9]

The resulting baseline 50-state emission inventories for Category 1 propulsion engines are given in Table 0-5.

Table 0-5 Baseline (50-State) Emissions for C1 Propulsion Engines (short tons)

YEAR	PM$_{10}$	PM$_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	13,328	12,928	335,561	9,488	9,010	55,303	36,201
2003	13,690	13,279	336,369	9,573	9,091	55,801	36,528
2004	13,807	13,393	332,798	9,561	9,080	55,722	36,862
2005	13,873	13,457	328,810	9,550	9,069	55,582	37,192
2006	13,872	13,456	324,900	9,540	9,060	55,450	36,827
2007	12,230	11,863	316,663	9,415	8,941	54,423	19,121
2008	10,961	10,632	308,524	9,291	8,824	53,405	6,299
2009	10,710	10,388	300,509	9,170	8,708	52,401	6,355
2010	10,304	9,995	292,651	9,051	8,595	51,414	4,705
2011	9,916	9,619	284,979	8,934	8,484	50,445	3,513
2012	9,471	9,187	277,551	8,821	8,377	49,497	1,862
2013	9,003	8,733	270,764	8,711	8,273	48,574	664
2014	8,587	8,330	264,634	8,606	8,173	47,680	799
2015	8,155	7,910	258,879	8,507	8,079	46,827	857
2016	7,718	7,487	253,538	8,415	7,992	46,023	865
2017	7,346	7,126	249,327	8,347	7,927	45,368	872
2018	7,058	6,846	246,339	8,304	7,886	44,879	879
2019	6,805	6,601	243,964	8,272	7,855	44,482	886
2020	6,632	6,433	242,764	8,269	7,852	44,301	893
2021	6,538	6,342	242,677	8,293	7,876	44,329	900
2022	6,470	6,276	242,990	8,326	7,907	44,423	907
2023	6,422	6,229	243,640	8,367	7,946	44,571	915
2024	6,388	6,197	244,563	8,414	7,990	44,760	923
2025	6,368	6,177	245,736	8,466	8,040	44,987	931
2026	6,359	6,168	247,141	8,523	8,094	45,248	939
2027	6,363	6,173	248,720	8,584	8,152	45,539	946
2028	6,381	6,190	250,474	8,649	8,214	45,861	954
2029	6,410	6,218	252,384	8,719	8,280	46,209	962
2030	6,451	6,258	254,450	8,792	8,349	46,583	970
2031	6,499	6,304	256,608	8,868	8,421	46,975	978
2032	6,552	6,356	258,851	8,946	8,495	47,385	986
2033	6,611	6,413	261,181	9,026	8,572	47,811	995
2034	6,671	6,471	263,532	9,107	8,649	48,241	1,006
2035	6,731	6,529	265,903	9,189	8,727	48,675	1,015
2036	6,791	6,588	268,297	9,272	8,805	49,114	1,023
2037	6,852	6,647	270,711	9,356	8,885	49,556	1,032
2038	6,914	6,707	273,148	9,440	8,965	50,002	1,040
2039	6,976	6,767	275,606	9,525	9,045	50,452	1,050
2040	7,039	6,828	278,086	9,610	9,127	50,906	1,059

3.1.2.2 Category 1 Auxiliary

The methodology and data sources for Category 1 marine auxiliary engines are essentially the same as those for Category 1 propulsion engines. For this source category, however, the PSR data for marine auxiliary engines and the certification data with the D2 auxiliary cycle[c] were used instead. The inventory inputs of base year population, average power, load factor, and activity for C1 auxiliary engines are given in Table 0-6 and Table 0-7. The baseline emission factors are given in Table 0-8 and Table 0-9.

For auxiliary engines, the load factor and activity estimates are 0.56 and 724 hours per year, respectively, for engines <560kW. These are the estimates for auxiliary marine engines provided by PSR. For engines >560kW, the load factor and activity estimates used are 0.65 and 2,500 hours per year, taken from the 1999 FRM.[6] The cut point of 560kW is that used for propulsion engines.

The median life for all C1 auxiliary engines is 17 years, which is the estimate provided by PSR. Estimates for the annual growth rate, PM deterioration factor, certification fuel sulfur levels, and BSFC are assumed to be the same as those for C1 propulsion engines.

The resulting baseline 50-state emission inventories for Category 1 auxiliary engines are given in Table 0-10.

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[c] The D2 steady-state duty cycle is designated for constant-speed engines.

Table 0-6 Inventory Inputs for C1 Auxiliary Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	9,786	44	0.56	724	0				9,786
DISP<0.9 AND >75KW	1,251	83	0.56	724	0				1,251
0.9<=DISP<1.2	11,933	109	0.56	724	0				11,933
1.2<=DISP<2.5	14,119	324	0.57	925	512	741	0.65	2,500	14,631
2.5<=DISP<3.5	785	332	0.56	724	74	882	0.65	2,500	859
3.5<=DISP<5.0	347	356	0.56	724	408	746	0.65	2,500	755
TOTAL	38,221				994				39,215

DISPLACEMENT CATEGORY	<35 KW/L								TOTAL POPULATION
	1000<KW≤1400				>1400KW*				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	0				0				0
2.5<=DISP<3.5	14	1,194	0.65	2,500	0				14
3.5<=DISP<5.0	268	1,119	0.65	2,500	96	1,527	0.65	2,500	364
TOTAL	282				96				378

Grand Total 38,503 1,090 39,593

* No populations ≥3700KW

Table 0-7 Inventory Inputs for C1 Auxiliary High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	<=600KW				600<KW≤1000				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	215	75	0.56	724	0				215
DISP<0.9 AND >75KW	218	141	0.56	724	0				218
0.9<=DISP<1.2	0				0				0
1.2<=DISP<2.5	0				0				0
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	0				0				0
TOTAL	433				0				433

DISPLACEMENT CATEGORY	≥35 KW/L								TOTAL POPULATION
	1000<KW≤1400				>1400KW*				
	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	2002 POPULATION	AVG KW	LOAD FACTOR	ACTIVITY, HOURS	
DISP<0.9 AND 37<KW<=75	0				0				0
DISP<0.9 AND >75KW	0				0				0
0.9<=DISP<1.2	11	1,231	0.65	2,500	0				11
1.2<=DISP<2.5	0				39	1,531	0.65	2,500	39
2.5<=DISP<3.5	0				0				0
3.5<=DISP<5.0	0				0				0
TOTAL	11				39				50
Grand Total	444				39				483

* No populations ≥3700KW

Table 0-8 Baseline PM_{10} and NO_x Emission Factors for C1 Auxiliary Engines*

DISPLACEMENT CATEGORY	PM_{10} G/KW-HR			NO_X G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.84	0.84	0.23	11	9.8	5.7
0.9<=DISP<1.2	0.53	0.53	0.21	10	9.8	5.4
1.2<=DISP<2.5	0.34	0.34	0.15	10	9.8	6.1
2.5<=DISP<3.5	0.32	0.32	0.15	10	9.1	6.1
3.5<=DISP<5.0	0.30	0.30	0.15	11	9.2	6.1

* Deterioration is applied to the PM emission factors (EFs); see text for details. The NO_x EFs are not subject to deterioration.

Table 0-9 Baseline HC and CO Emission Factors for C1 Auxiliary Engines*

DISPLACEMENT CATEGORY	HC G/KW-HR			CO G/KW-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
DISP<0.9	0.41	0.41	0.41	2.0	2.0	1.6
0.9<=DISP<1.2	0.32	0.32	0.32	1.7	1.7	0.8
1.2<=DISP<2.5	0.27	0.27	0.21	1.5	1.5	0.9
2.5<=DISP<3.5	0.27	0.27	0.21	1.5	1.5	0.9
3.5<=DISP<5.0	0.27	0.27	0.21	1.8	1.8	0.9

* The HC and CO emission factors (EFs) are not subject to deterioration.

Table 0-10 Baseline (50-State) Emissions for C1 Auxiliary Engines (short tons)

YEAR	PM$_{10}$	PM $_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	2,714	2,632	60,641	1,767	1,678	9,624	6,553
2003	2,773	2,690	60,959	1,783	1,693	9,710	6,613
2004	2,791	2,708	60,482	1,785	1,696	9,668	6,673
2005	2,786	2,703	59,774	1,788	1,698	9,585	6,733
2006	2,769	2,686	59,073	1,791	1,700	9,503	6,667
2007	2,482	2,407	58,048	1,787	1,697	9,331	3,461
2008	2,263	2,195	57,030	1,783	1,693	9,160	1,140
2009	2,230	2,163	56,020	1,779	1,690	8,989	1,150
2010	2,170	2,105	55,022	1,776	1,686	8,820	852
2011	2,115	2,052	54,038	1,773	1,684	8,654	636
2012	2,052	1,990	53,069	1,770	1,681	8,489	337
2013	1,993	1,933	52,118	1,767	1,678	8,327	120
2014	1,952	1,893	51,185	1,765	1,676	8,167	145
2015	1,907	1,850	50,277	1,763	1,674	8,010	155
2016	1,860	1,805	49,399	1,761	1,673	7,857	157
2017	1,806	1,752	48,589	1,760	1,672	7,708	158
2018	1,746	1,693	47,849	1,759	1,671	7,563	159
2019	1,685	1,634	47,160	1,759	1,671	7,426	160
2020	1,625	1,576	46,531	1,760	1,672	7,298	162
2021	1,576	1,528	46,079	1,764	1,675	7,198	163
2022	1,543	1,497	45,840	1,771	1,681	7,134	164
2023	1,520	1,474	45,706	1,778	1,689	7,088	166
2024	1,504	1,459	45,683	1,788	1,698	7,066	167
2025	1,495	1,451	45,756	1,799	1,709	7,067	169
2026	1,489	1,445	45,875	1,811	1,720	7,077	170
2027	1,486	1,441	46,035	1,824	1,732	7,094	171
2028	1,484	1,440	46,228	1,837	1,745	7,117	173
2029	1,484	1,440	46,452	1,851	1,758	7,145	174
2030	1,486	1,441	46,703	1,865	1,771	7,178	176
2031	1,489	1,444	46,980	1,880	1,785	7,215	177
2032	1,493	1,448	47,283	1,895	1,800	7,257	179
2033	1,499	1,454	47,611	1,911	1,815	7,303	180
2034	1,506	1,461	47,962	1,927	1,830	7,353	182
2035	1,514	1,469	48,332	1,943	1,845	7,407	184
2036	1,524	1,478	48,721	1,960	1,861	7,464	185
2037	1,535	1,489	49,126	1,977	1,878	7,524	187
2038	1,547	1,501	49,553	1,995	1,894	7,588	188
2039	1,561	1,514	49,991	2,013	1,911	7,654	190
2040	1,574	1,527	50,436	2,031	1,928	7,721	192

3.1.2.3 Category 2 Propulsion

The methodology used for C2 propulsion engines is the same as that used for C1 propulsion engines, as described in section 3.1.1. However, the engine population, average rated power, load factor and engine activity terms shown in Equation 1 of that section were consolidated into a single term for total kW-hr/year for all C2 vessels.[10] The total kW-hr value for C2 propulsion engines in 2002 was estimated at 30,246,809,539 kW-hr. The total kW-hr value was then allocated to the necessary displacement and horsepower categories, using the PSR engine data.

The median life for all C2 propulsion engines is 23 years.[11] The emission factors used for all C2 propulsion engines are largely those we used for the original commercial marine rulemaking analysis.[6] The one exception to this is for Tier 1 NOx, which was updated based on an analysis of 2006 certification data. The C2 emission factors are shown in Table 0-11. Estimates for the annual growth rate, PM deterioration factor, and certification fuel sulfur levels are assumed to be the same as those for C1 propulsion engines.

Table 0-11 Baseline Emission Factors for C2 Engines (g/kW-hr)*

Tier	PM_{10}	NO_x	HC	CO
BASE	0.32	13.36	0.134	2.48
TIER 1	0.32	10.55	0.134	2.48
TIER 2	0.32	8.33	0.134	2.00

* Deterioration is applied to the PM emission factors (EFs); see text for details. The NOx, HC and CO EFs are not subject to deterioration.

The resulting baseline 50-state emission inventories for Category 2 propulsion engines are given in Table 0-12.

Table 0-12 Baseline (50-State) Emissions for C2 Propulsion Engines (short tons)

YEAR	PM$_{10}$	PM $_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	12,850	12,464	432,306	4,701	4,464	82,621	36,868
2003	13,112	12,719	431,973	4,743	4,504	83,364	37,193
2004	13,376	12,975	431,683	4,786	4,545	84,115	37,528
2005	13,641	13,232	431,417	4,829	4,586	84,872	37,866
2006	13,907	13,490	431,195	4,872	4,627	85,635	38,207
2007	14,174	13,748	427,380	4,916	4,669	85,621	38,550
2008	14,436	14,003	423,601	4,960	4,711	85,611	38,837
2009	14,706	14,264	419,857	5,005	4,753	85,605	39,204
2010	14,975	14,525	416,169	5,050	4,796	85,609	39,559
2011	15,245	14,787	412,537	5,096	4,839	85,621	39,920
2012	15,515	15,050	408,943	5,141	4,883	85,639	40,278
2013	15,727	15,255	405,428	5,188	4,927	85,665	39,905
2014	14,475	14,041	401,970	5,234	4,971	85,701	21,334
2015	13,635	13,226	398,593	5,281	5,016	85,746	7,888
2016	13,883	13,466	395,295	5,329	5,061	85,800	7,958
2017	13,986	13,566	392,101	5,377	5,106	85,864	6,238
2018	14,127	13,703	388,988	5,425	5,152	85,937	4,998
2019	14,228	13,801	386,000	5,474	5,199	86,020	3,277
2020	14,365	13,934	383,155	5,523	5,245	86,116	2,031
2021	14,613	14,175	380,458	5,573	5,293	86,222	2,185
2022	14,850	14,405	377,990	5,623	5,340	86,341	2,258
2023	15,059	14,607	376,313	5,674	5,388	86,475	2,279
2024	15,243	14,786	375,430	5,725	5,437	86,626	2,299
2025	15,423	14,960	374,784	5,777	5,486	86,790	2,319
2026	15,599	15,131	374,343	5,829	5,535	86,974	2,339
2027	15,772	15,299	374,086	5,881	5,585	87,178	2,359
2028	15,943	15,465	374,039	5,934	5,635	87,406	2,379
2029	16,114	15,630	374,219	5,987	5,686	87,672	2,399
2030	16,283	15,794	375,126	6,041	5,737	88,078	2,421
2031	16,451	15,957	376,727	6,096	5,789	88,623	2,442
2032	16,618	16,120	378,567	6,150	5,841	89,207	2,463
2033	16,786	16,282	380,573	6,206	5,893	89,820	2,485
2034	16,952	16,444	382,749	6,262	5,946	90,457	2,507
2035	17,119	16,605	385,076	6,318	6,000	91,119	2,529
2036	17,286	16,767	387,519	6,375	6,054	91,799	2,551
2037	17,453	16,929	390,097	6,432	6,108	92,500	2,573
2038	17,620	17,091	392,794	6,490	6,163	93,219	2,595
2039	17,787	17,253	395,609	6,549	6,219	93,956	2,618
2040	17,954	17,416	398,527	6,607	6,275	94,707	2,641

3.1.2.4 Under 37 kW Propulsion and Auxiliary

Category 1 commercial marine engines are defined as being greater than or equal to (≥) 37kW and less than (<) 5.0 liters/cylinder; however, there are commercial marine engines <37kW. The majority of these small power engines are used as auxiliary engines, although there are some propulsion engines that fall into this category. Commercial marine engines <37kW are covered under this proposal; therefore, inventories have been estimated.

Emissions were estimated using a special version of the NONROAD2005 model, with Source Classification Codes (SCCs) and associated inputs added for both the commercial and auxiliary engines. An SCC of 2280002030 was assigned to the <37kW propulsion engines, with an SCC of 2280002040 assigned to the <37kW auxiliary engines.

The inventory inputs of base year population, average power, load factor, activity, and median life are given in Table 0-13 below. These inputs were generated using the same methodology and data sources as the C1 propulsion and C1 auxiliary categories. Horsepower (hp) is used as the unit for power in the NONROAD model, so the inputs for power and emission factors are hp and g/hp-hr, respectively. The 2002 base year populations are assigned to one or more of the following hp categories in NONROAD: 0-11, 11-16, 16-25, 25-40, and 40-50. The propulsion engines all fall within the 25-40hp category, whereas there are auxiliary engines in each hp category. The average power values in the table below are population-weighted estimates.

Table 0-13 Inventory Inputs for <37kW Commercial Marine Diesel Engines

INPUTS	PROPULSION	AUXILIARY
2002 POPULATION	1,232	67,708
AVG HP	34.8	24.9
LOAD FACTOR	0.45	0.56
ACTIVITY, HOURS	943	724
MEDIAN LIFE, YEARS	13	17

The baseline emission factors are given in Table 0-14 and Table 0-15. These engines are subject to EPA nonroad diesel regulations that have established two tiers of emission standards.[12] Tier 1 phased in from 1999-2000, depending on the horsepower category, with Tier 2 phased in from 2004-2005. The "Base" entries in the tables refer to emissions from pre-controlled engines. These emission factors are used for both propulsion and auxiliary engines.

Table 0-14 Baseline PM_{10} and NO_x Emission Factors and Deterioration Factors for <37kW Commercial Marine Diesel Engines

HP RANGE	PM_{10} G/HP-HR			NO_X G/HP-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
0-11	1.00	0.45	0.38	10.00	5.23	4.39
11-16	0.90	0.27	0.19	8.50	4.44	3.63
16-25	0.90	0.27	0.19	8.50	4.44	3.63
25-50	0.80	0.34	0.23	6.90	4.73	3.71
DF ("A")	0.473	0.473	0.473	0.024	0.024	0.009

Table 0-15 Baseline HC and CO Emission Factors and Deterioration Factors for <37kW Commercial Marine Diesel Engines

HP RANGE	HC G/HP-HR			CO G/HP-HR		
	BASE	TIER 1	TIER 2	BASE	TIER 1	TIER 2
0-11	1.50	0.76	0.68	5.00	4.11	4.11
11-16	1.70	0.44	0.21	5.00	2.16	2.16
16-25	1.70	0.44	0.21	5.00	2.16	2.16
25-50	1.80	0.28	0.54	5.00	1.53	1.53
DF ("A")	0.047	0.036	0.034	0.185	0.101	0.101

The emission factors for the base and Tier 1 technology types are consistent with those used in the NONROAD model.[2] Tier 2 emission factors were estimated using nonroad engine certification data. The deterioration factors by pollutant and technology type are also given in the tables above. The deterioration factors are those used for diesel engines in the NONROAD model.[2]

The certification fuel sulfur levels are 3300ppm for the base and Tier 1 technology type and 350ppm for Tier 2. Brake specific fuel consumption (BSFC) values were taken from the NONROAD model and are 0.408 lb/hp-hr for all hp categories.[2] The annual population growth rate is 1.009, which is the growth rate used for all commercial diesel engines.

The resulting baseline 50-state emission inventories for <37kW commercial marine engines (propulsion and auxiliary combined) are given in Table 0-16.

Table 0-16 Baseline (50-State) Emissions for <37kW Commercial Marine Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	728	706	5,517	1,273	1,209	3,783	731
2003	710	689	5,448	1,222	1,161	3,680	738
2004	692	671	5,350	1,179	1,120	3,576	745
2005	671	651	5,229	1,128	1,071	3,460	752
2006	648	629	5,101	1,075	1,021	3,339	745
2007	596	578	4,973	1,022	970	3,216	387
2008	551	534	4,846	969	920	3,093	128
2009	526	511	4,719	916	870	2,970	129
2010	499	484	4,594	864	821	2,846	95
2011	472	458	4,472	813	772	2,724	71
2012	444	431	4,351	763	725	2,603	38
2013	417	404	4,234	715	679	2,484	14
2014	392	381	4,120	668	634	2,369	16
2015	368	357	4,011	624	592	2,259	18
2016	348	337	3,917	588	559	2,170	18
2017	332	322	3,846	564	535	2,109	18
2018	320	311	3,790	546	518	2,063	18
2019	310	301	3,744	531	504	2,027	18
2020	301	292	3,704	519	493	1,997	18
2021	294	285	3,675	507	482	1,972	18
2022	288	279	3,659	497	472	1,952	18
2023	284	275	3,654	491	466	1,940	19
2024	280	272	3,654	485	461	1,932	19
2025	278	269	3,658	481	457	1,926	19
2026	276	268	3,670	479	455	1,926	19
2027	275	267	3,685	478	454	1,929	19
2028	275	267	3,703	478	454	1,934	19
2029	275	267	3,723	478	454	1,942	20
2030	275	267	3,746	479	455	1,952	20
2031	276	268	3,771	481	457	1,963	20
2032	278	269	3,798	484	460	1,977	20
2033	279	271	3,828	488	463	1,992	20
2034	282	273	3,859	492	467	2,009	21
2035	284	275	3,891	496	471	2,026	21
2036	286	278	3,924	500	475	2,044	21
2037	289	280	3,958	504	479	2,061	21
2038	291	282	3,992	509	483	2,079	21
2039	294	285	4,026	513	487	2,097	21
2040	296	287	4,061	517	491	2,115	22

3.1.2.5 Commercial Marine Diesel Baseline Inventory Summary

3.1.2.5.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

Table 0-17 thru Table 0-22 present the resulting 50-state consolidated commercial marine baseline inventories by pollutant and category, for calendar years 2002-2040.

3.1.2.5.2 Air Toxics Emissions

The baseline air toxics inventories for the consolidated commercial marine diesel engines were taken from the Mobile Source Air Toxics Rule (MSAT)[5] and are provided in Table 0-23. Inventories are provided for calendar years 1999, 2010, 2015, 2020, and 2030.

Table 0-17 Baseline (50-State) PM$_{10}$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	13,328	2,714	16,041	12,850	728	29,619
2003	13,690	2,773	16,463	13,112	710	30,285
2004	13,807	2,791	16,598	13,376	692	30,666
2005	13,873	2,786	16,659	13,641	671	30,972
2006	13,872	2,769	16,641	13,907	648	31,196
2007	12,230	2,482	14,712	14,174	596	29,481
2008	10,961	2,263	13,224	14,436	551	28,211
2009	10,710	2,230	12,940	14,706	526	28,172
2010	10,304	2,170	12,474	14,975	499	27,948
2011	9,916	2,115	12,031	15,245	472	27,748
2012	9,471	2,052	11,522	15,515	444	27,482
2013	9,003	1,993	10,996	15,727	417	27,140
2014	8,587	1,952	10,539	14,475	392	25,406
2015	8,155	1,907	10,062	13,635	368	24,066
2016	7,718	1,860	9,579	13,883	348	23,809
2017	7,346	1,806	9,152	13,986	332	23,470
2018	7,058	1,746	8,804	14,127	320	23,250
2019	6,805	1,685	8,490	14,228	310	23,028
2020	6,632	1,625	8,257	14,365	301	22,923
2021	6,538	1,576	8,114	14,613	294	23,021
2022	6,470	1,543	8,013	14,850	288	23,151
2023	6,422	1,520	7,942	15,059	284	23,284
2024	6,388	1,504	7,893	15,243	280	23,416
2025	6,368	1,495	7,864	15,423	278	23,564
2026	6,359	1,489	7,849	15,599	276	23,724
2027	6,363	1,486	7,849	15,772	275	23,897
2028	6,381	1,484	7,865	15,943	275	24,083
2029	6,410	1,484	7,895	16,114	275	24,283
2030	6,451	1,486	7,937	16,283	275	24,495
2031	6,499	1,489	7,988	16,451	276	24,715
2032	6,552	1,493	8,045	16,618	278	24,941
2033	6,611	1,499	8,110	16,786	279	25,175
2034	6,671	1,506	8,177	16,952	282	25,411
2035	6,731	1,514	8,245	17,119	284	25,648
2036	6,791	1,524	8,315	17,286	286	25,887
2037	6,852	1,535	8,387	17,453	289	26,129
2038	6,914	1,547	8,461	17,620	291	26,372
2039	6,976	1,561	8,537	17,787	294	26,617
2040	7,039	1,574	8,613	17,954	296	26,864

Table 0-18 Baseline (50-State) PM$_{2.5}$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	12,928	2,632	15,560	12,464	706	28,730
2003	13,279	2,690	15,969	12,719	689	29,377
2004	13,393	2,708	16,100	12,975	671	29,746
2005	13,457	2,703	16,159	13,232	651	30,042
2006	13,456	2,686	16,142	13,490	629	30,260
2007	11,863	2,407	14,270	13,748	578	28,596
2008	10,632	2,195	12,827	14,003	534	27,364
2009	10,388	2,163	12,552	14,264	511	27,327
2010	9,995	2,105	12,100	14,525	484	27,109
2011	9,619	2,052	11,670	14,787	458	26,916
2012	9,187	1,990	11,177	15,050	431	26,657
2013	8,733	1,933	10,666	15,255	404	26,326
2014	8,330	1,893	10,223	14,041	381	24,644
2015	7,910	1,850	9,760	13,226	357	23,344
2016	7,487	1,805	9,291	13,466	337	23,095
2017	7,126	1,752	8,878	13,566	322	22,766
2018	6,846	1,693	8,539	13,703	311	22,553
2019	6,601	1,634	8,235	13,801	301	22,337
2020	6,433	1,576	8,009	13,934	292	22,236
2021	6,342	1,528	7,871	14,175	285	22,330
2022	6,276	1,497	7,773	14,405	279	22,457
2023	6,229	1,474	7,703	14,607	275	22,585
2024	6,197	1,459	7,656	14,786	272	22,714
2025	6,177	1,451	7,628	14,960	269	22,857
2026	6,168	1,445	7,613	15,131	268	23,012
2027	6,173	1,441	7,614	15,299	267	23,180
2028	6,190	1,440	7,629	15,465	267	23,361
2029	6,218	1,440	7,658	15,630	267	23,555
2030	6,258	1,441	7,699	15,794	267	23,760
2031	6,304	1,444	7,748	15,957	268	23,973
2032	6,356	1,448	7,804	16,120	269	24,193
2033	6,413	1,454	7,867	16,282	271	24,420
2034	6,471	1,461	7,932	16,444	273	24,648
2035	6,529	1,469	7,998	16,605	275	24,879
2036	6,588	1,478	8,066	16,767	278	25,111
2037	6,647	1,489	8,136	16,929	280	25,345
2038	6,707	1,501	8,207	17,091	282	25,581
2039	6,767	1,514	8,281	17,253	285	25,819
2040	6,828	1,527	8,355	17,416	287	26,058

Table 0-19 Baseline (50-State) NO_x Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	335,561	60,641	396,202	432,306	5,517	834,025
2003	336,369	60,959	397,328	431,973	5,448	834,749
2004	332,798	60,482	393,280	431,683	5,350	830,313
2005	328,810	59,774	388,583	431,417	5,229	825,229
2006	324,900	59,073	383,973	431,195	5,101	820,269
2007	316,663	58,048	374,710	427,380	4,973	807,063
2008	308,524	57,030	365,554	423,601	4,846	794,001
2009	300,509	56,020	356,529	419,857	4,719	781,105
2010	292,651	55,022	347,673	416,169	4,594	768,436
2011	284,979	54,038	339,017	412,537	4,472	756,026
2012	277,551	53,069	330,621	408,943	4,351	743,915
2013	270,764	52,118	322,882	405,428	4,234	732,544
2014	264,634	51,185	315,819	401,970	4,120	721,910
2015	258,879	50,277	309,156	398,593	4,011	711,760
2016	253,538	49,399	302,937	395,295	3,917	702,150
2017	249,327	48,589	297,916	392,101	3,846	693,862
2018	246,339	47,849	294,188	388,988	3,790	686,966
2019	243,964	47,160	291,123	386,000	3,744	680,867
2020	242,764	46,531	289,295	383,155	3,704	676,154
2021	242,677	46,079	288,756	380,458	3,675	672,889
2022	242,990	45,840	288,831	377,990	3,659	670,480
2023	243,640	45,706	289,346	376,313	3,654	669,313
2024	244,563	45,683	290,245	375,430	3,654	669,329
2025	245,736	45,756	291,492	374,784	3,658	669,934
2026	247,141	45,875	293,016	374,343	3,670	671,029
2027	248,720	46,035	294,755	374,086	3,685	672,525
2028	250,474	46,228	296,703	374,039	3,703	674,445
2029	252,384	46,452	298,836	374,219	3,723	676,778
2030	254,450	46,703	301,153	375,126	3,746	680,025
2031	256,608	46,980	303,588	376,727	3,771	684,087
2032	258,851	47,283	306,134	378,567	3,798	688,500
2033	261,181	47,611	308,792	380,573	3,828	693,193
2034	263,532	47,962	311,494	382,749	3,859	698,103
2035	265,903	48,332	314,236	385,076	3,891	703,203
2036	268,297	48,721	317,017	387,519	3,924	708,460
2037	270,711	49,126	319,838	390,097	3,958	713,892
2038	273,148	49,553	322,701	392,794	3,992	719,486
2039	275,606	49,991	325,597	395,609	4,026	725,233
2040	278,086	50,436	328,522	398,527	4,061	731,111

Table 0-20 Baseline (50-State) VOC Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	9,488	1,767	11,255	4,701	1,273	17,229
2003	9,573	1,783	11,356	4,743	1,222	17,321
2004	9,561	1,785	11,346	4,786	1,179	17,311
2005	9,550	1,788	11,338	4,829	1,128	17,295
2006	9,540	1,791	11,331	4,872	1,075	17,278
2007	9,415	1,787	11,202	4,916	1,022	17,140
2008	9,291	1,783	11,074	4,960	969	17,003
2009	9,170	1,779	10,949	5,005	916	16,870
2010	9,051	1,776	10,826	5,050	864	16,741
2011	8,934	1,773	10,707	5,096	813	16,615
2012	8,821	1,770	10,591	5,141	763	16,495
2013	8,711	1,767	10,479	5,188	715	16,381
2014	8,606	1,765	10,371	5,234	668	16,273
2015	8,507	1,763	10,270	5,281	624	16,175
2016	8,415	1,761	10,176	5,329	588	16,094
2017	8,347	1,760	10,107	5,377	564	16,048
2018	8,304	1,759	10,063	5,425	546	16,034
2019	8,272	1,759	10,031	5,474	531	16,036
2020	8,269	1,760	10,029	5,523	519	16,071
2021	8,293	1,764	10,057	5,573	507	16,137
2022	8,326	1,771	10,097	5,623	497	16,218
2023	8,367	1,778	10,145	5,674	491	16,310
2024	8,414	1,788	10,202	5,725	485	16,412
2025	8,466	1,799	10,265	5,777	481	16,523
2026	8,523	1,811	10,334	5,829	479	16,642
2027	8,584	1,824	10,408	5,881	478	16,767
2028	8,649	1,837	10,487	5,934	478	16,898
2029	8,719	1,851	10,570	5,987	478	17,035
2030	8,792	1,865	10,657	6,041	479	17,178
2031	8,868	1,880	10,748	6,096	481	17,325
2032	8,946	1,895	10,841	6,150	484	17,476
2033	9,026	1,911	10,937	6,206	488	17,631
2034	9,107	1,927	11,034	6,262	492	17,788
2035	9,189	1,943	11,133	6,318	496	17,947
2036	9,272	1,960	11,232	6,375	500	18,107
2037	9,356	1,977	11,333	6,432	504	18,269
2038	9,440	1,995	11,435	6,490	509	18,433
2039	9,525	2,013	11,537	6,549	513	18,599
2040	9,610	2,031	11,641	6,607	517	18,766

Table 0-21 Baseline (50-State) CO Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	55,303	9,624	64,927	82,621	3,783	151,331
2003	55,801	9,710	65,511	83,364	3,680	152,556
2004	55,722	9,668	65,390	84,115	3,576	153,080
2005	55,582	9,585	65,167	84,872	3,460	153,499
2006	55,450	9,503	64,954	85,635	3,339	153,928
2007	54,423	9,331	63,754	85,621	3,216	152,591
2008	53,405	9,160	62,565	85,611	3,093	151,269
2009	52,401	8,989	61,391	85,605	2,970	149,966
2010	51,414	8,820	60,235	85,609	2,846	148,690
2011	50,445	8,654	59,099	85,621	2,724	147,444
2012	49,497	8,489	57,986	85,639	2,603	146,227
2013	48,574	8,327	56,901	85,665	2,484	145,050
2014	47,680	8,167	55,847	85,701	2,369	143,917
2015	46,827	8,010	54,837	85,746	2,259	142,842
2016	46,023	7,857	53,880	85,800	2,170	141,851
2017	45,368	7,708	53,076	85,864	2,109	141,049
2018	44,879	7,563	52,443	85,937	2,063	140,443
2019	44,482	7,426	51,908	86,020	2,027	139,954
2020	44,301	7,298	51,599	86,116	1,997	139,712
2021	44,329	7,198	51,527	86,222	1,972	139,720
2022	44,423	7,134	51,557	86,341	1,952	139,851
2023	44,571	7,088	51,659	86,475	1,940	140,073
2024	44,760	7,066	51,827	86,626	1,932	140,384
2025	44,987	7,067	52,054	86,790	1,926	140,771
2026	45,248	7,077	52,325	86,974	1,926	141,226
2027	45,539	7,094	52,633	87,178	1,929	141,740
2028	45,861	7,117	52,978	87,406	1,934	142,318
2029	46,209	7,145	53,354	87,672	1,942	142,968
2030	46,583	7,178	53,761	88,078	1,952	143,791
2031	46,975	7,215	54,191	88,623	1,963	144,776
2032	47,385	7,257	54,642	89,207	1,977	145,825
2033	47,811	7,303	55,114	89,820	1,992	146,926
2034	48,241	7,353	55,595	90,457	2,009	148,060
2035	48,675	7,407	56,082	91,119	2,026	149,227
2036	49,114	7,464	56,577	91,799	2,044	150,419
2037	49,556	7,524	57,079	92,500	2,061	151,640
2038	50,002	7,588	57,589	93,219	2,079	152,887
2039	50,452	7,654	58,105	93,956	2,097	154,158
2040	50,906	7,721	58,627	94,707	2,115	155,449

Table 0-22 Baseline (50-State) SO_2 Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	36,201	6,553	42,754	36,868	731	80,353
2003	36,528	6,613	43,141	37,193	738	81,073
2004	36,862	6,673	43,535	37,528	745	81,808
2005	37,192	6,733	43,925	37,866	752	82,543
2006	36,827	6,667	43,493	38,207	745	82,445
2007	19,121	3,461	22,583	38,550	387	61,520
2008	6,299	1,140	7,440	38,837	128	46,404
2009	6,355	1,150	7,506	39,204	129	46,838
2010	4,705	852	5,557	39,559	95	45,212
2011	3,513	636	4,148	39,920	71	44,139
2012	1,862	337	2,199	40,278	38	42,515
2013	664	120	784	39,905	14	40,702
2014	799	145	943	21,334	16	22,293
2015	857	155	1,012	7,888	18	8,917
2016	865	157	1,021	7,958	18	8,997
2017	872	158	1,030	6,238	18	7,286
2018	879	159	1,038	4,998	18	6,054
2019	886	160	1,046	3,277	18	4,342
2020	893	162	1,055	2,031	18	3,104
2021	900	163	1,063	2,185	18	3,267
2022	907	164	1,072	2,258	18	3,348
2023	915	166	1,081	2,279	19	3,378
2024	923	167	1,090	2,299	19	3,408
2025	931	169	1,099	2,319	19	3,437
2026	939	170	1,109	2,339	19	3,466
2027	946	171	1,118	2,359	19	3,496
2028	954	173	1,127	2,379	19	3,526
2029	962	174	1,136	2,399	20	3,555
2030	970	176	1,146	2,421	20	3,586
2031	978	177	1,155	2,442	20	3,617
2032	986	179	1,165	2,463	20	3,649
2033	995	180	1,175	2,485	20	3,680
2034	1,006	182	1,188	2,507	21	3,716
2035	1,015	184	1,198	2,529	21	3,748
2036	1,023	185	1,208	2,551	21	3,780
2037	1,032	187	1,218	2,573	21	3,812
2038	1,040	188	1,228	2,595	21	3,845
2039	1,050	190	1,240	2,618	21	3,880
2040	1,059	192	1,251	2,641	22	3,913

Table 0-23 Air Toxics Emissions for Commercial Marine Diesel Engines (short tons)

HAP	1999	2010	2015	2020	2030
BENZENE	530	556	559	572	624
FORMALDEHYDE	3,897	4,091	4,112	4,208	4,587
ACETALDEHYDE	1,937	2,033	2,044	2,091	2,280
1,3-BUTADIENE	6	6	6	6	7
ACROLEIN	75	79	79	81	89
NAPHTHALENE	43	39	37	36	40
POM	11	10	9	9	10

3.1.3 Control Inventory Development

This section describes how the controlled emission inventories were developed for the commercial marine diesel categories: Category 1 propulsion, Category 1 auxiliary, Category 2 propulsion, and less than (<) 37kW. This section will only describe the modifications to the emission factors, since the other inventory inputs are unchanged.

3.1.3.1 Control Scenario(s) Modeled

For commercial marine diesel engines, there are two tiers of proposed PM and either combined HC+NO_x or NO_x only standards for the control scenario that was modeled.

The proposed emission standards for Category 1 engines are summarized in Table 0-24 and Table 0-25. These standards apply to both propulsion and auxiliary engines. There are separate emission standards for standard and high power density engines. Standard power density engines are less than 35 kW per liter (kW/L), and the high power density engines are greater than or equal to 35 kW/L. Within these power density categories, there are also separate standards that vary by power and displacement. There are no Tier 4 standards for engines less than 600 kW. Standards are not shown in cases where there is zero engine population.

The proposed emission standards for Category 2 engines are summarized in Table 0-26. The standards vary by displacement and power. All Category 2 engines are considered to be standard power density engines. These engines are subject to both Tier 3 and Tier 4 emission standards.

The proposed emission standards for <37kW propulsion and auxiliary engines are given in Table 0-27. This category is subject to Tier 3 standards which begin in 2009.

Table 0-24 Proposed Standards (g/kW-hr) for C1 Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L											
	<=600KW						600<KW≤1000					
		TIER 3			TIER 4			TIER 3			TIER 4	
	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	7.5	0.30	NO TIER 4 STANDARDS			NO ENGINES IN THESE CATEGORIES					
	2014	4.7										
DISP<0.9 AND >75KW	2012	5.4	0.13									
0.9<=DISP<1.2	2013	5.4	0.12									
1.2<=DISP<2.5	2014	5.6	0.11				2014	5.6	0.11	2018	1.7	0.04
	2018		0.09									
2.5<=DISP<3.5	2013	5.6	0.11				2013	5.6	0.11	2018	1.7	0.04
	2018		0.09									
3.5<=DISP<5.0	2012	5.8	0.11				2012	5.8	0.11	2018	1.7	0.04
	2018		0.09									

DISPLACEMENT CATEGORY	<35 KW/L											
	1000<KW≤1400						>1400KW					
		TIER 3			TIER 4			TIER 3			TIER 4	
	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES						NO ENGINES IN THESE CATEGORIES					
DISP<0.9 AND >75KW												
0.9<=DISP<1.2												
1.2<=DISP<2.5	2014	5.6	0.11	2017	1.7	0.04						
2.5<=DISP<3.5	2013	5.6	0.11	2017	1.7	0.04						
3.5<=DISP<5.0	2012	5.8	0.11	2017	1.7	0.04	2012	5.8	0.11	2016	1.7	0.04

Table 0-25 Proposed Standards (g/kW-hr) for C1 High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L											
	<=600KW						600<KW≤1000					
		TIER 3			TIER 4			TIER 3			TIER 4	
	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	7.5	0.30	NO TIER 4 STANDARDS			NO ENGINES IN THESE CATEGORIES					
	2014	4.7										
DISP<0.9 AND >75KW	2012	5.8	0.15									
0.9<=DISP<1.2	2013	5.8	0.13									
1.2<=DISP<2.5	2014	5.8	0.12				2014	5.6	0.11	2018	1.7	0.04
2.5<=DISP<3.5	NO ENGINES						NO ENGINES IN THESE CATEGORIES					
3.5<=DISP<5.0												

DISPLACEMENT CATEGORY	≥35 KW/L											
	1000<KW≤1400						>1400KW					
		TIER 3			TIER 4			TIER 3			TIER 4	
	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM	YEAR	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES						NO ENGINES IN THESE CATEGORIES					
DISP<0.9 AND >75KW												
0.9<=DISP<1.2	2013	5.4	0.12	2017	1.7	0.04						
1.2<=DISP<2.5	NO ENGINES IN THESE CATEGORIES						2014	5.6	0.11	2016	1.7	0.04
2.5<=DISP<3.5							NO ENGINES IN THIS CATEGORY					
3.5<=DISP<5.0	2012	5.8	0.11	2017	1.7	0.04	2012	5.8	0.11	2016	1.7	0.04

Table 0-26 Proposed Standards (g/kW-hr) for C2 Engines

DISPLACEMENT CATEGORY	YEAR	TIER 3		YEAR	TIER 4	
		NO$_X$+HC	PM		NO$_X$	PM
5.0<=DISP<15 AND <600KW	2013	6.2	0.13			
5.0<=DISP<15 AND 600≤KW<1000	2013	6.2	0.13	2018	1.7	0.04
5.0<=DISP<15 AND 1000≤KW<1400	2013	6.2	0.13	2017	1.7	0.04
5.0<=DISP<15 AND 1400≤KW<3700	2013	6.2	0.13	2016	1.7	0.04
5.0<=DISP<15 AND ≥3700KW				2014	1.7	0.12
				2017		0.05
15.0<=DISP<20.0 AND <1400KW	NO ENGINES IN THIS CATEGORY					
15.0<=DISP<20.0 AND 1400≤KW<3300	2014	7.0	0.34	2016	1.7	0.04
15.0<=DISP<20.0 AND 3300≤KW<3700	NO ENGINES IN THIS CATEGORY					
15.0<=DISP<20.0 AND ≥3700KW				2014	1.7	0.25
				2017		0.05
20.0<=DISP<30.0	NO ENGINES IN THIS CATEGORY					

Table 0-27 Proposed Standards (g/hp-hr) for <37kW Commercial Marine Diesel Engines

HP RANGE	YEAR	TIER 3	
		NO$_X$+HC	PM
0-25	2009	5.6	0.30
25-50	2009	5.6	0.22
	2014	3.5	0.22

3.1.3.2 Category 1 Propulsion

The modeled Tier 3 and Tier 4 emission factors corresponding to the emission standards are shown in Table 0-28 and Table 0-29. These emission factors are derived by applying the appropriate relative reductions from the Tier 2 standard to the Tier 2 emission factors, using the following equations:

Equation 3 Tier 3 EF = (Tier 3 std/Tier 2 std) x Tier 2 EF

Equation 4 Tier 4 EF = (Tier 4 std/Tier 2 std) x Tier 2 EF

For NO$_x$, the standards used in the above equations are the combined HC+NO$_x$ standards. For HC and PM, the PM standards are used.

The resulting control case 50-state emission inventories for Category 1 propulsion engines are given in Table 0-30.

3.1.3.3 Category 1 Auxiliary

The modeled Tier 3 and Tier 4 emission factors for Category 1 auxiliary engines are shown in Table 0-31 and Table 0-32. The methodology described above for Category 1 propulsion engines was used to derive these emission factors.

The resulting control case 50-state emission inventories for Category 1 auxiliary engines are given in Table 0-33.

Table 0-28 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Propulsion Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L											
	<=600KW				600<KW≤1000							
	YEAR	TIER 3			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	0.30	5.70	0.17	NO ENGINES IN THESE CATEGORIES							
	2014		3.56									
DISP<0.9 AND >75KW	2012	0.14	4.08	0.08								
0.9<=DISP<1.2	2013	0.13	4.54	0.05								
1.2<=DISP<2.5	2014	0.10	4.69	0.07	2014	0.10	4.69	0.07	2018	0.04	1.30	0.03
	2018			0.061								
2.5<=DISP<3.5	2013	0.10	4.69	0.07	2013	0.10	4.69	0.07	2018	0.04	1.30	0.03
	2018			0.061								
3.5<=DISP<5.0	2012	0.10	4.81	0.07	2012	0.10	4.81	0.07	2018	0.04	1.30	0.03
	2018			0.061								

DISPLACEMENT CATEGORY	<35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2																
1.2<=DISP<2.5	2014	0.10	4.69	0.07	2017	0.04	1.3	0.03								
2.5<=DISP<3.5	2013	0.10	4.69	0.07	2017	0.04	1.3	0.03								
3.5<=DISP<5.0	2012	0.10	4.81	0.07	2017	0.04	1.3	0.03	2012	0.10	4.81	0.07	2016	0.04	1.3	0.03

Table 0-29 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Propulsion High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L											
	<=600KW				600<KW≤1000							
	YEAR	TIER 3			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES				NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW	2012	0.15	4.38	0.08								
0.9<=DISP<1.2	2013	0.14	4.89	0.05								
1.2<=DISP<2.5	2014	0.11	4.81	0.08	2014	0.10	4.69	0.07	2018	0.04	1.3	0.03
2.5<=DISP<3.5	NO ENGINES				NO ENGINES IN THESE CATEGORIES							
3.5<=DISP<5.0												

DISPLACEMENT CATEGORY	≥35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2																
1.2<=DISP<2.5																
2.5<=DISP<3.5																
3.5<=DISP<5.0	2012	0.10	4.81	0.07	2017	0.04	1.3	0.03	2012	0.10	4.81	0.07	2016	0.04	1.3	0.03

Table 0-30 Control Case (50-State) Emissions for C1 Propulsion Engines (short tons)

YEAR	PM$_{10}$	PM$_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	13,328	12,928	335,561	9,488	9,010	55,303	36,201
2003	13,690	13,279	336,369	9,573	9,091	55,801	36,528
2004	13,807	13,393	332,798	9,561	9,080	55,722	36,862
2005	13,873	13,457	328,810	9,550	9,069	55,582	37,192
2006	13,872	13,456	324,900	9,540	9,060	55,450	36,827
2007	12,230	11,863	316,663	9,415	8,941	54,423	19,121
2008	10,961	10,632	308,524	9,291	8,824	53,405	6,299
2009	10,709	10,388	300,509	9,169	8,708	52,401	6,355
2010	10,304	9,995	292,651	9,050	8,594	51,414	4,705
2011	9,916	9,618	284,979	8,933	8,483	50,445	3,513
2012	9,409	9,127	276,209	8,708	8,270	49,497	1,862
2013	8,859	8,593	267,453	8,433	8,008	48,574	664
2014	8,291	8,042	257,691	8,042	7,637	47,680	799
2015	7,700	7,469	248,317	7,658	7,273	46,827	857
2016	7,065	6,853	236,292	7,228	6,864	46,023	865
2017	6,463	6,269	223,265	6,784	6,443	45,368	872
2018	5,911	5,734	209,717	6,334	6,015	44,879	879
2019	5,388	5,226	196,847	5,898	5,601	44,482	886
2020	4,938	4,790	185,242	5,496	5,219	44,301	893
2021	4,562	4,425	174,843	5,126	4,868	44,329	900
2022	4,208	4,082	164,971	4,772	4,532	44,423	907
2023	3,873	3,756	155,589	4,433	4,210	44,571	915
2024	3,552	3,446	146,696	4,111	3,904	44,760	923
2025	3,263	3,165	138,521	3,826	3,634	44,987	931
2026	3,013	2,923	131,195	3,589	3,408	45,248	939
2027	2,808	2,724	124,763	3,400	3,229	45,539	946
2028	2,644	2,565	119,185	3,252	3,089	45,861	954
2029	2,512	2,436	114,708	3,134	2,976	46,209	962
2030	2,417	2,344	111,660	3,049	2,896	46,583	970
2031	2,352	2,282	109,766	2,991	2,841	46,975	978
2032	2,310	2,241	108,624	2,953	2,804	47,385	986
2033	2,284	2,215	107,896	2,927	2,780	47,811	995
2034	2,265	2,197	107,443	2,911	2,764	48,241	1,006
2035	2,254	2,186	107,233	2,902	2,756	48,675	1,015
2036	2,248	2,181	107,236	2,901	2,755	49,114	1,023
2037	2,250	2,182	107,444	2,906	2,760	49,556	1,032
2038	2,256	2,189	107,834	2,919	2,772	50,002	1,040
2039	2,268	2,200	108,376	2,936	2,788	50,452	1,050
2040	2,282	2,214	109,054	2,957	2,808	50,906	1,059

Table 0-31 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Auxiliary Standard Power Density Engines

DISPLACEMENT CATEGORY	<35 KW/L											
	≤600KW				600<KW≤1000							
	YEAR	TIER 3			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	0.30	5.70	0.17	NO ENGINES IN THESE CATEGORIES							
	2014		3.56									
DISP<0.9 AND >75KW	2012	0.14	4.08	0.08								
0.9<=DISP<1.2	2013	0.13	4.02	0.08								
1.2<=DISP<2.5	2014	0.11	4.77	0.08	2014	0.11	4.77	0.08	2018	0.04	1.3	0.03
	2018			0.070								
2.5<=DISP<3.5	2013	0.11	4.77	0.08	2013	0.11	4.77	0.08	2018	0.04	1.3	0.03
	2018			0.070								
3.5<=DISP<5.0	2012	0.11	4.89	0.08	2012	0.11	4.89	0.08	2018	0.04	1.3	0.03
	2018			0.070								

DISPLACEMENT CATEGORY	<35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2																
1.2<=DISP<2.5																
2.5<=DISP<3.5	2013	0.11	4.77	0.08	2017	0.04	1.3	0.03								
3.5<=DISP<5.0	2012	0.11	4.89	0.08	2017	0.04	1.3	0.03	2012	0.11	4.89	0.08	2016	0.04	1.3	0.03

Table 0-32 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C1 Auxiliary High Power Density Engines

DISPLACEMENT CATEGORY	≥35 KW/L											
	≤600KW				600<KW≤1000							
	YEAR	TIER 3			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	2009	0.30	5.70	0.17	NO ENGINES IN THESE CATEGORIES							
	2014		3.56									
DISP<0.9 AND >75KW	2012	0.15	4.38	0.08								
0.9<=DISP<1.2	NO ENGINES IN THESE CATEGORIES											
1.2<=DISP<2.5												
2.5<=DISP<3.5												
3.5<=DISP<5.0												

DISPLACEMENT CATEGORY	≥35 KW/L															
	1000<KW≤1400								>1400KW							
	YEAR	TIER 3			YEAR	TIER 4			YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM		HC	NO_X	PM
DISP<0.9 AND 37<KW<=75	NO ENGINES IN THESE CATEGORIES								NO ENGINES IN THESE CATEGORIES							
DISP<0.9 AND >75KW																
0.9<=DISP<1.2	2013	0.13	4.02	0.08	2017	0.04	1.3	0.03								
1.2<=DISP<2.5	NO ENGINES IN THESE CATEGORIES								2014	0.11	4.77	0.08	2016	0.04	1.3	0.03
2.5<=DISP<3.5									NO ENGINES IN THESE CATEGORIES							
3.5<=DISP<5.0																

Table 0-33 Control Case (50-State) Emissions for C1 Auxiliary Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	2,714	2,632	60,641	1,767	1,678	9,624	6,553
2003	2,773	2,690	60,959	1,783	1,693	9,710	6,613
2004	2,791	2,708	60,482	1,785	1,696	9,668	6,673
2005	2,786	2,703	59,774	1,788	1,698	9,585	6,733
2006	2,769	2,686	59,073	1,791	1,700	9,503	6,667
2007	2,482	2,407	58,048	1,787	1,697	9,331	3,461
2008	2,263	2,195	57,030	1,783	1,693	9,160	1,140
2009	2,229	2,162	56,020	1,778	1,688	8,989	1,150
2010	2,169	2,104	55,022	1,773	1,684	8,820	852
2011	2,113	2,049	54,038	1,768	1,679	8,654	636
2012	2,042	1,981	52,949	1,753	1,664	8,489	337
2013	1,971	1,912	51,796	1,727	1,640	8,327	120
2014	1,902	1,845	50,317	1,677	1,593	8,167	145
2015	1,829	1,774	48,863	1,628	1,546	8,010	155
2016	1,751	1,698	47,349	1,577	1,497	7,857	157
2017	1,663	1,613	45,754	1,523	1,446	7,708	158
2018	1,561	1,514	43,895	1,463	1,389	7,563	159
2019	1,458	1,414	42,089	1,403	1,333	7,426	160
2020	1,354	1,314	40,347	1,345	1,278	7,298	162
2021	1,261	1,224	38,787	1,290	1,225	7,198	163
2022	1,184	1,149	37,444	1,239	1,176	7,134	164
2023	1,116	1,082	36,210	1,188	1,129	7,088	166
2024	1,054	1,022	35,096	1,141	1,083	7,066	167
2025	998	968	34,089	1,095	1,040	7,067	169
2026	945	917	33,138	1,052	999	7,077	170
2027	895	868	32,243	1,010	959	7,094	171
2028	847	822	31,399	970	921	7,117	173
2029	803	779	30,630	935	888	7,145	174
2030	764	741	29,948	905	859	7,178	176
2031	733	711	29,388	882	838	7,215	177
2032	708	687	28,939	866	823	7,257	179
2033	687	667	28,572	853	810	7,303	180
2034	669	649	28,303	843	801	7,353	182
2035	656	637	28,159	836	794	7,407	184
2036	647	628	28,117	832	790	7,464	185
2037	641	622	28,123	830	788	7,524	187
2038	637	618	28,176	829	787	7,588	188
2039	635	616	28,259	829	788	7,654	190
2040	635	616	28,367	831	789	7,721	192

3.1.3.4 Category 2 Propulsion

The modeled Tier 3 and Tier 4 emission factors for Category 2 propulsion engines are shown in Table 0-34. The methodology described above for Category 1 propulsion engines was used to derive these emission factors.

The resulting control case 50-state emission inventories for Category 2 propulsion engines are given in Table 0-35.

Table 0-34 Control PM_{10}, NOx, and HC Emission Factors (g/kW-hr) for C2 Engines

DISPLACEMENT CATEGORY	YEAR	TIER 3			YEAR	TIER 4		
		HC	NO_X	PM		HC	NO_X	PM
5.0<=DISP<15 AND <600KW	2013	0.07	5.97	0.11				
5.0<=DISP<15 AND 600≤KW<1000	2013	0.07	5.97	0.11	2018	0.02	1.3	0.03
5.0<=DISP<15 AND 1000≤KW<1400	2013	0.07	5.97	0.11	2017	0.02	1.3	0.03
5.0<=DISP<15 AND 1400≤KW<3700	2013	0.07	5.97	0.11	2016	0.02	1.3	0.03
5.0<=DISP<15 AND ≥3700KW					2014	0.06	1.3	0.10
					2017	0.03	1.3	0.04
15.0<=DISP<20.0 AND 1400≤KW<3300	2014	0.09	6.77	0.30	2016	0.01	1.3	0.04
15.0<=DISP<20.0 AND >3700KW					2014	0.07	1.3	0.23
					2017	0.01	1.3	0.05

Table 0-35 Control Case (50-State) Emissions for C2 Propulsion Engines

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	12,850	12,464	432,306	4,701	4,464	82,621	36,868
2003	13,112	12,719	431,973	4,743	4,504	83,364	37,193
2004	13,376	12,975	431,683	4,786	4,545	84,115	37,528
2005	13,641	13,232	431,417	4,829	4,586	84,872	37,866
2006	13,907	13,490	431,195	4,872	4,627	85,635	38,207
2007	14,174	13,748	427,380	4,916	4,669	85,621	38,550
2008	14,436	14,003	423,601	4,960	4,711	85,611	38,837
2009	14,706	14,264	419,857	5,005	4,753	85,605	39,204
2010	14,975	14,525	416,169	5,050	4,796	85,609	39,559
2011	15,245	14,787	412,537	5,096	4,839	85,621	39,920
2012	15,515	15,050	408,943	5,141	4,883	85,639	40,278
2013	15,569	15,102	404,127	5,150	4,891	85,665	39,905
2014	14,031	13,610	392,503	5,082	4,826	85,701	21,334
2015	12,996	12,606	380,939	5,014	4,761	85,746	7,888
2016	12,865	12,479	365,582	4,896	4,650	85,800	7,817
2017	12,482	12,107	350,179	4,729	4,491	85,864	5,901
2018	12,130	11,766	334,823	4,563	4,333	85,937	4,574
2019	11,748	11,396	319,586	4,396	4,175	86,020	2,963
2020	11,394	11,052	304,523	4,230	4,017	86,116	1,888
2021	11,108	10,775	289,618	4,066	3,861	86,222	1,976
2022	10,804	10,480	274,971	3,901	3,705	86,341	1,995
2023	10,465	10,151	261,143	3,738	3,550	86,475	1,975
2024	10,094	9,791	248,136	3,576	3,396	86,626	1,954
2025	9,710	9,419	235,393	3,415	3,243	86,790	1,934
2026	9,315	9,035	222,855	3,254	3,090	86,974	1,913
2027	8,909	8,641	210,526	3,094	2,938	87,178	1,894
2028	8,493	8,238	198,433	2,935	2,787	87,406	1,874
2029	8,071	7,829	186,645	2,777	2,637	87,672	1,855
2030	7,644	7,414	175,655	2,622	2,490	88,078	1,836
2031	7,211	6,995	165,474	2,468	2,344	88,623	1,818
2032	6,776	6,573	155,629	2,317	2,200	89,207	1,800
2033	6,342	6,152	146,134	2,169	2,060	89,820	1,783
2034	5,909	5,732	136,983	2,025	1,923	90,457	1,766
2035	5,482	5,318	128,247	1,885	1,790	91,119	1,750
2036	5,089	4,936	120,169	1,757	1,669	91,799	1,735
2037	4,756	4,613	113,689	1,651	1,568	92,500	1,721
2038	4,466	4,332	108,659	1,562	1,484	93,219	1,709
2039	4,220	4,093	104,710	1,488	1,413	93,956	1,700
2040	4,039	3,918	101,729	1,434	1,362	94,707	1,699

3.1.3.5 Less than 37 kW Propulsion and Auxiliary

The modeled Tier 3 emission factors for less than (<) 37kW commercial marine diesel engines are given in Table 0-36. These emission factors apply to both propulsion and auxiliary engines. For HC, the methodology described for Category 1 propulsion engines was used. For PM, a 20 percent compliance margin was applied to the Tier 3 standard; however, if the resulting emission factor was greater than the corresponding Tier 2 emission factor, the Tier 2 value was used for Tier 3. Since the proposed rule does not result in NO_x control for this category, the Tier 3 NO_x emission factors were set equal to Tier 2.

Table 0-36 Control PM_{10}, NO_x, and HC Emission Factors (g/hp-hr) for <37kW Commercial Marine Diesel Engines

HP RANGE	YEAR	TIER 3		
		HC	NO_X	PM
0-11	2009	0.43	4.39	0.24
11-16	2009	0.21	3.63	0.19
	2014	0.21	2.32	0.19
16-25	2009	0.21	3.63	0.19
	2014	0.21	2.32	0.19
25-50	2009	0.41	3.71	0.18
	2014	0.41	2.32	0.18

The resulting control case 50-state emission inventories for <37kW propulsion and auxiliary engines are given in Table 0-37.

3.1.3.6 Commercial Marine Diesel Control Inventory Summary

3.1.3.6.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

Table 0-38 thru Table 0-43 present the resulting 50-state consolidated commercial marine control case inventories for each pollutant and category, for calendar years 2002-2040.

3.1.3.6.2 Air Toxics Emissions

The control case air toxics inventories for commercial marine diesel engines are provided in Table 0-44. The gaseous air toxics are assumed to be controlled proportionately to VOC, whereas POM is controlled proportionately to PM.

Table 0-37 Control Case (50-State) Emissions for <37kW Commercial Marine Engines (short tons)

YEAR	PM_{10}	$PM_{2.5}$	NO_X	VOC	HC	CO	SO_2
2002	728	706	5,517	1,273	1,209	3,783	731
2003	710	689	5,448	1,222	1,161	3,680	738
2004	692	671	5,350	1,179	1,120	3,576	745
2005	671	651	5,229	1,128	1,071	3,460	752
2006	648	629	5,101	1,075	1,021	3,339	745
2007	596	578	4,973	1,022	970	3,216	387
2008	551	534	4,846	969	920	3,093	128
2009	524	509	4,719	911	865	2,970	129
2010	495	480	4,594	853	810	2,846	95
2011	466	452	4,472	797	757	2,724	71
2012	437	424	4,351	741	704	2,603	38
2013	409	397	4,234	688	653	2,484	14
2014	383	371	4,073	636	604	2,369	16
2015	357	346	3,917	586	556	2,259	18
2016	334	324	3,777	545	518	2,170	18
2017	317	308	3,658	515	489	2,109	18
2018	303	294	3,556	492	467	2,063	18
2019	291	282	3,462	472	448	2,027	18
2020	280	272	3,377	454	432	1,997	18
2021	271	263	3,301	438	416	1,972	18
2022	263	255	3,240	423	402	1,952	18
2023	257	249	3,188	411	390	1,940	19
2024	252	244	3,144	401	381	1,932	19
2025	248	240	3,103	393	373	1,926	19
2026	244	237	3,070	387	368	1,926	19
2027	242	235	3,042	383	364	1,929	19
2028	241	234	3,018	381	361	1,934	19
2029	240	233	2,998	379	360	1,942	20
2030	240	233	2,982	378	359	1,952	20
2031	240	233	2,978	378	359	1,963	20
2032	241	234	2,983	380	360	1,977	20
2033	242	235	2,993	381	362	1,992	20
2034	244	236	3,007	384	365	2,009	21
2035	245	238	3,022	387	367	2,026	21
2036	247	240	3,040	389	370	2,044	21
2037	249	242	3,058	392	372	2,061	21
2038	251	244	3,079	395	375	2,079	21
2039	253	246	3,100	398	378	2,097	21
2040	255	248	3,123	402	381	2,115	22

Table 0-38 Control Case (50-State) PM$_{10}$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	13,328	2,714	16,041	12,850	728	29,619
2003	13,690	2,773	16,463	13,112	710	30,285
2004	13,807	2,791	16,598	13,376	692	30,666
2005	13,873	2,786	16,659	13,641	671	30,972
2006	13,872	2,769	16,641	13,907	648	31,196
2007	12,230	2,482	14,712	14,174	596	29,481
2008	10,961	2,263	13,224	14,436	551	28,211
2009	10,709	2,229	12,939	14,706	524	28,169
2010	10,304	2,169	12,472	14,975	495	27,942
2011	9,916	2,113	12,029	15,245	466	27,740
2012	9,409	2,042	11,451	15,515	437	27,404
2013	8,859	1,971	10,830	15,569	409	26,808
2014	8,291	1,902	10,192	14,031	383	24,606
2015	7,700	1,829	9,528	12,996	357	22,881
2016	7,065	1,751	8,816	12,865	334	22,015
2017	6,463	1,663	8,126	12,482	317	20,925
2018	5,911	1,561	7,472	12,130	303	19,905
2019	5,388	1,458	6,845	11,748	291	18,885
2020	4,938	1,354	6,292	11,394	280	17,967
2021	4,562	1,261	5,824	11,108	271	17,203
2022	4,208	1,184	5,393	10,804	263	16,460
2023	3,873	1,116	4,988	10,465	257	15,710
2024	3,552	1,054	4,606	10,094	252	14,952
2025	3,263	998	4,262	9,710	248	14,219
2026	3,013	945	3,959	9,315	244	13,518
2027	2,808	895	3,704	8,909	242	12,855
2028	2,644	847	3,491	8,493	241	12,225
2029	2,512	803	3,315	8,071	240	11,626
2030	2,417	764	3,181	7,644	240	11,065
2031	2,352	733	3,085	7,211	240	10,537
2032	2,310	708	3,019	6,776	241	10,036
2033	2,284	687	2,971	6,342	242	9,555
2034	2,265	669	2,934	5,909	244	9,087
2035	2,254	656	2,910	5,482	245	8,638
2036	2,248	647	2,896	5,089	247	8,232
2037	2,250	641	2,891	4,756	249	7,895
2038	2,256	637	2,894	4,466	251	7,611
2039	2,268	635	2,903	4,220	253	7,376
2040	2,282	635	2,917	4,039	255	7,211

Table 0-39 Control Case (50-State) $PM_{2.5}$ Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	12,928	2,632	15,560	12,464	706	28,730
2003	13,279	2,690	15,969	12,719	689	29,377
2004	13,393	2,708	16,100	12,975	671	29,746
2005	13,457	2,703	16,159	13,232	651	30,042
2006	13,456	2,686	16,142	13,490	629	30,260
2007	11,863	2,407	14,270	13,748	578	28,596
2008	10,632	2,195	12,827	14,003	534	27,364
2009	10,388	2,162	12,551	14,264	509	27,324
2010	9,995	2,104	12,098	14,525	480	27,104
2011	9,618	2,049	11,668	14,787	452	26,908
2012	9,127	1,981	11,107	15,050	424	26,582
2013	8,593	1,912	10,505	15,102	397	26,004
2014	8,042	1,845	9,887	13,610	371	23,868
2015	7,469	1,774	9,242	12,606	346	22,195
2016	6,853	1,698	8,551	12,479	324	21,354
2017	6,269	1,613	7,882	12,107	308	20,297
2018	5,734	1,514	7,248	11,766	294	19,308
2019	5,226	1,414	6,640	11,396	282	18,318
2020	4,790	1,314	6,103	11,052	272	17,428
2021	4,425	1,224	5,649	10,775	263	16,687
2022	4,082	1,149	5,231	10,480	255	15,966
2023	3,756	1,082	4,838	10,151	249	15,239
2024	3,446	1,022	4,468	9,791	244	14,503
2025	3,165	968	4,134	9,419	240	13,793
2026	2,923	917	3,840	9,035	237	13,113
2027	2,724	868	3,592	8,641	235	12,469
2028	2,565	822	3,386	8,238	234	11,858
2029	2,436	779	3,215	7,829	233	11,277
2030	2,344	741	3,086	7,414	233	10,733
2031	2,282	711	2,993	6,995	233	10,221
2032	2,241	687	2,928	6,573	234	9,735
2033	2,215	667	2,882	6,152	235	9,269
2034	2,197	649	2,846	5,732	236	8,815
2035	2,186	637	2,823	5,318	238	8,378
2036	2,181	628	2,809	4,936	240	7,985
2037	2,182	622	2,804	4,613	242	7,658
2038	2,189	618	2,807	4,332	244	7,383
2039	2,200	616	2,816	4,093	246	7,155
2040	2,214	616	2,829	3,918	248	6,995

Table 0-40 Control Case (50-State) NO_x Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	335,561	60,641	396,202	432,306	5,517	834,025
2003	336,369	60,959	397,328	431,973	5,448	834,749
2004	332,798	60,482	393,280	431,683	5,350	830,313
2005	328,810	59,774	388,583	431,417	5,229	825,229
2006	324,900	59,073	383,973	431,195	5,101	820,269
2007	316,663	58,048	374,710	427,380	4,973	807,063
2008	308,524	57,030	365,554	423,601	4,846	794,001
2009	300,509	56,020	356,529	419,857	4,719	781,105
2010	292,651	55,022	347,673	416,169	4,594	768,436
2011	284,979	54,038	339,017	412,537	4,472	756,026
2012	276,209	52,949	329,158	408,943	4,351	742,453
2013	267,453	51,796	319,249	404,127	4,234	727,609
2014	257,691	50,317	308,007	392,503	4,073	704,584
2015	248,317	48,863	297,181	380,939	3,917	682,037
2016	236,292	47,349	283,640	365,582	3,777	652,999
2017	223,265	45,754	269,020	350,179	3,658	622,856
2018	209,717	43,895	253,612	334,823	3,556	591,991
2019	196,847	42,089	238,936	319,586	3,462	561,984
2020	185,242	40,347	225,589	304,523	3,377	533,489
2021	174,843	38,787	213,630	289,618	3,301	506,550
2022	164,971	37,444	202,415	274,971	3,240	480,625
2023	155,589	36,210	191,800	261,143	3,188	456,131
2024	146,696	35,096	181,792	248,136	3,144	433,072
2025	138,521	34,089	172,610	235,393	3,103	411,106
2026	131,195	33,138	164,333	222,855	3,070	390,259
2027	124,763	32,243	157,006	210,526	3,042	370,574
2028	119,185	31,399	150,584	198,433	3,018	352,035
2029	114,708	30,630	145,338	186,645	2,998	334,981
2030	111,660	29,948	141,608	175,655	2,982	320,245
2031	109,766	29,388	139,154	165,474	2,978	307,605
2032	108,624	28,939	137,563	155,629	2,983	296,175
2033	107,896	28,572	136,468	146,134	2,993	285,596
2034	107,443	28,303	135,746	136,983	3,007	275,735
2035	107,233	28,159	135,392	128,247	3,022	266,661
2036	107,236	28,117	135,352	120,169	3,040	258,561
2037	107,444	28,123	135,566	113,689	3,058	252,314
2038	107,834	28,176	136,009	108,659	3,079	247,747
2039	108,376	28,259	136,635	104,710	3,100	244,445
2040	109,054	28,367	137,421	101,729	3,123	242,273

Table 0-41 Control Case (50-State) VOC Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	9,488	1,767	11,255	4,701	1,273	17,229
2003	9,573	1,783	11,356	4,743	1,222	17,321
2004	9,561	1,785	11,346	4,786	1,179	17,311
2005	9,550	1,788	11,338	4,829	1,128	17,295
2006	9,540	1,791	11,331	4,872	1,075	17,278
2007	9,415	1,787	11,202	4,916	1,022	17,140
2008	9,291	1,783	11,074	4,960	969	17,003
2009	9,169	1,778	10,947	5,005	911	16,863
2010	9,050	1,773	10,823	5,050	853	16,726
2011	8,933	1,768	10,701	5,096	797	16,594
2012	8,708	1,753	10,461	5,141	741	16,344
2013	8,433	1,727	10,160	5,150	688	15,998
2014	8,042	1,677	9,719	5,082	636	15,437
2015	7,658	1,628	9,286	5,014	586	14,885
2016	7,228	1,577	8,805	4,896	545	14,246
2017	6,784	1,523	8,307	4,729	515	13,551
2018	6,334	1,463	7,796	4,563	492	12,851
2019	5,898	1,403	7,302	4,396	472	12,169
2020	5,496	1,345	6,841	4,230	454	11,526
2021	5,126	1,290	6,416	4,066	438	10,920
2022	4,772	1,239	6,010	3,901	423	10,335
2023	4,433	1,188	5,621	3,738	411	9,771
2024	4,111	1,141	5,252	3,576	401	9,229
2025	3,826	1,095	4,922	3,415	393	8,729
2026	3,589	1,052	4,640	3,254	387	8,281
2027	3,400	1,010	4,410	3,094	383	7,887
2028	3,252	970	4,223	2,935	381	7,538
2029	3,134	935	4,068	2,777	379	7,225
2030	3,049	905	3,953	2,622	378	6,953
2031	2,991	882	3,874	2,468	378	6,720
2032	2,953	866	3,819	2,317	380	6,516
2033	2,927	853	3,781	2,169	381	6,331
2034	2,911	843	3,754	2,025	384	6,162
2035	2,902	836	3,738	1,885	387	6,010
2036	2,901	832	3,733	1,757	389	5,880
2037	2,906	830	3,736	1,651	392	5,779
2038	2,919	829	3,748	1,562	395	5,705
2039	2,936	829	3,765	1,488	398	5,652
2040	2,957	831	3,787	1,434	402	5,623

Table 0-42 Control Case (50-State) CO Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	55,303	9,624	64,927	82,621	3,783	151,331
2003	55,801	9,710	65,511	83,364	3,680	152,556
2004	55,722	9,668	65,390	84,115	3,576	153,080
2005	55,582	9,585	65,167	84,872	3,460	153,499
2006	55,450	9,503	64,954	85,635	3,339	153,928
2007	54,423	9,331	63,754	85,621	3,216	152,591
2008	53,405	9,160	62,565	85,611	3,093	151,269
2009	52,401	8,989	61,391	85,605	2,970	149,966
2010	51,414	8,820	60,235	85,609	2,846	148,690
2011	50,445	8,654	59,099	85,621	2,724	147,444
2012	49,497	8,489	57,986	85,639	2,603	146,227
2013	48,574	8,327	56,901	85,665	2,484	145,050
2014	47,680	8,167	55,847	85,701	2,369	143,917
2015	46,827	8,010	54,837	85,746	2,259	142,842
2016	46,023	7,857	53,880	85,800	2,170	141,851
2017	45,368	7,708	53,076	85,864	2,109	141,049
2018	44,879	7,563	52,443	85,937	2,063	140,443
2019	44,482	7,426	51,908	86,020	2,027	139,954
2020	44,301	7,298	51,599	86,116	1,997	139,712
2021	44,329	7,198	51,527	86,222	1,972	139,720
2022	44,423	7,134	51,557	86,341	1,952	139,851
2023	44,571	7,088	51,659	86,475	1,940	140,073
2024	44,760	7,066	51,827	86,626	1,932	140,384
2025	44,987	7,067	52,054	86,790	1,926	140,771
2026	45,248	7,077	52,325	86,974	1,926	141,226
2027	45,539	7,094	52,633	87,178	1,929	141,740
2028	45,861	7,117	52,978	87,406	1,934	142,318
2029	46,209	7,145	53,354	87,672	1,942	142,968
2030	46,583	7,178	53,761	88,078	1,952	143,791
2031	46,975	7,215	54,191	88,623	1,963	144,776
2032	47,385	7,257	54,642	89,207	1,977	145,825
2033	47,811	7,303	55,114	89,820	1,992	146,926
2034	48,241	7,353	55,595	90,457	2,009	148,060
2035	48,675	7,407	56,082	91,119	2,026	149,227
2036	49,114	7,464	56,577	91,799	2,044	150,419
2037	49,556	7,524	57,079	92,500	2,061	151,640
2038	50,002	7,588	57,589	93,219	2,079	152,887
2039	50,452	7,654	58,105	93,956	2,097	154,158
2040	50,906	7,721	58,627	94,707	2,115	155,449

Table 0-43 Control Case (50-State) SO_2 Emissions for Commercial Marine Diesel Engines (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2002	36,201	6,553	42,754	36,868	731	80,353
2003	36,528	6,613	43,141	37,193	738	81,073
2004	36,862	6,673	43,535	37,528	745	81,808
2005	37,192	6,733	43,925	37,866	752	82,543
2006	36,827	6,667	43,493	38,207	745	82,445
2007	19,121	3,461	22,583	38,550	387	61,520
2008	6,299	1,140	7,440	38,837	128	46,404
2009	6,355	1,150	7,506	39,204	129	46,839
2010	4,705	852	5,557	39,559	95	45,212
2011	3,513	636	4,148	39,920	71	44,139
2012	1,862	337	2,199	40,278	38	42,515
2013	664	120	784	39,905	14	40,702
2014	799	145	943	21,334	16	22,293
2015	857	155	1,012	7,888	18	8,917
2016	865	157	1,021	7,817	18	8,855
2017	872	158	1,030	5,901	18	6,949
2018	879	159	1,038	4,574	18	5,630
2019	886	160	1,046	2,963	18	4,028
2020	893	162	1,055	1,888	18	2,961
2021	900	163	1,063	1,976	18	3,058
2022	907	164	1,072	1,995	18	3,085
2023	915	166	1,081	1,975	19	3,074
2024	923	167	1,090	1,954	19	3,063
2025	931	169	1,099	1,934	19	3,052
2026	939	170	1,109	1,913	19	3,041
2027	946	171	1,118	1,894	19	3,031
2028	954	173	1,127	1,874	19	3,020
2029	962	174	1,136	1,855	20	3,010
2030	970	176	1,146	1,836	20	3,002
2031	978	177	1,155	1,818	20	2,993
2032	986	179	1,165	1,800	20	2,985
2033	995	180	1,175	1,783	20	2,978
2034	1,006	182	1,188	1,766	21	2,975
2035	1,015	184	1,198	1,750	21	2,969
2036	1,023	185	1,208	1,735	21	2,964
2037	1,032	187	1,218	1,721	21	2,961
2038	1,040	188	1,228	1,709	21	2,958
2039	1,050	190	1,240	1,700	21	2,962
2040	1,059	192	1,251	1,699	22	2,971

Table 0-44 Control Case (50-State) Air Toxic Emissions for Commercial Marine Diesel Engines (short tons)

HAP	2010	2015	2020	2030
BENZENE	556	515	410	252
FORMALDEHYDE	4,088	3,785	3,018	1,857
ACETALDEHYDE	2,032	1,881	1,500	923
1,3-BUTADIENE	6	5	4	3
ACROLEIN	79	73	58	36
NAPHTHALENE	38	34	26	16
POM	10	9	7	4

3.1.4 Projected Commercial Marine Emission Reductions of Proposal

The $PM_{2.5}$, NO_x, and VOC emission reductions for each category and calendar year are presented in Table 0-45 thru Table 0-47. The air toxic emission reductions by pollutant and calendar year are given in Table 0-48.

Table 0-45 Projected Commercial Marine $PM_{2.5}$ Emission Reductions (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2008	0	0	0	0	0	0
2009	0	1	1	0	2	3
2010	0	2	2	0	4	6
2011	0	2	3	0	5	8
2012	60	9	69	0	6	76
2013	140	21	161	153	8	321
2014	288	49	336	431	9	776
2015	441	76	518	620	11	1,149
2016	634	106	740	988	13	1,740
2017	856	139	995	1,459	15	2,469
2018	1,112	179	1,292	1,937	16	3,245
2019	1,375	220	1,595	2,405	18	4,019
2020	1,643	262	1,905	2,882	20	4,808
2021	1,917	305	2,221	3,400	22	5,644
2022	2,194	348	2,542	3,925	24	6,491
2023	2,473	392	2,865	4,456	26	7,347
2024	2,751	437	3,188	4,995	28	8,210
2025	3,012	482	3,494	5,541	29	9,064
2026	3,245	528	3,773	6,096	31	9,899
2027	3,449	573	4,021	6,658	32	10,711
2028	3,625	618	4,243	7,227	33	11,503
2029	3,782	661	4,442	7,801	33	12,277
2030	3,914	700	4,613	8,380	34	13,027
2031	4,022	733	4,755	8,962	35	13,752
2032	4,115	761	4,876	9,546	35	14,458
2033	4,198	787	4,985	10,130	36	15,151
2034	4,274	811	5,085	10,712	37	15,834
2035	4,343	832	5,175	11,288	37	16,500
2036	4,407	850	5,257	11,831	38	17,126
2037	4,465	867	5,332	12,316	38	17,686
2038	4,518	882	5,400	12,759	39	18,198
2039	4,568	897	5,465	13,160	39	18,664
2040	4,614	911	5,525	13,498	40	19,063

Table 0-46 Projected Commercial Marine NO_x Emission Reductions (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2008	0	0	0	0	0	0
2009	0	0	0	0	0	0
2010	0	0	0	0	0	0
2011	0	0	0	0	0	0
2012	1,342	121	1,463	0	0	1,463
2013	3,311	322	3,633	1,301	0	4,935
2014	6,944	868	7,812	9,467	47	17,326
2015	10,562	1,414	11,976	17,654	94	29,723
2016	17,246	2,051	19,297	29,714	141	49,151
2017	26,061	2,835	28,896	41,922	188	71,006
2018	36,621	3,954	40,576	54,165	235	94,975
2019	47,117	5,071	52,187	66,413	281	118,882
2020	57,522	6,184	63,705	78,633	328	142,666
2021	67,833	7,292	75,126	90,840	374	166,339
2022	78,019	8,397	86,416	103,020	420	189,855
2023	88,051	9,495	97,546	115,170	465	213,181
2024	97,867	10,586	108,453	127,293	510	236,257
2025	107,215	11,667	118,882	139,391	555	258,828
2026	115,946	12,737	128,683	151,488	599	280,771
2027	123,957	13,792	137,749	163,559	643	301,951
2028	131,290	14,829	146,119	175,606	685	322,410
2029	137,676	15,822	153,498	187,573	726	341,797
2030	142,790	16,755	159,545	199,471	764	359,780
2031	146,842	17,592	164,434	211,253	794	376,481
2032	150,228	18,343	168,571	222,938	815	392,324
2033	153,285	19,039	172,324	234,439	835	407,598
2034	156,089	19,659	175,748	245,767	852	422,367
2035	158,671	20,173	178,844	256,829	869	436,542
2036	161,061	20,604	181,665	267,350	884	449,899
2037	163,268	21,004	184,271	276,408	899	461,578
2038	165,314	21,377	186,692	284,135	913	471,739
2039	167,230	21,732	188,962	290,899	926	480,787
2040	169,033	22,069	191,102	296,798	938	488,838

Table 0-47 Projected Commercial Marine VOC Emission Reductions (short tons)

YEAR	C1 PROPULSION	C1 AUXILIARY	C1 TOTAL	C2 PROPULSION	<37KW	TOTAL
2008	0	0	0	0	0	0
2009	0	2	2	0	5	7
2010	1	3	4	0	11	14
2011	1	5	6	0	16	22
2012	113	17	130	0	22	152
2013	279	40	319	37	27	383
2014	564	88	652	152	32	837
2015	849	135	984	268	38	1,290
2016	1,187	185	1,372	433	43	1,848
2017	1,563	237	1,800	648	49	2,497
2018	1,970	297	2,267	863	54	3,183
2019	2,374	356	2,730	1,078	59	3,867
2020	2,773	415	3,188	1,293	64	4,545
2021	3,167	474	3,640	1,508	70	5,218
2022	3,555	532	4,087	1,722	75	5,883
2023	3,934	590	4,524	1,936	79	6,539
2024	4,303	647	4,950	2,149	84	7,183
2025	4,639	704	5,343	2,362	89	7,794
2026	4,934	760	5,694	2,575	92	8,360
2027	5,184	814	5,998	2,787	95	8,880
2028	5,397	867	6,264	2,999	97	9,360
2029	5,585	917	6,501	3,210	99	9,811
2030	5,743	961	6,704	3,420	101	10,225
2031	5,876	998	6,874	3,628	103	10,605
2032	5,993	1,029	7,022	3,834	105	10,960
2033	6,099	1,058	7,157	4,037	106	11,300
2034	6,197	1,084	7,281	4,237	108	11,625
2035	6,287	1,107	7,394	4,433	109	11,936
2036	6,371	1,128	7,499	4,618	111	12,228
2037	6,449	1,147	7,596	4,781	112	12,490
2038	6,521	1,166	7,687	4,928	114	12,728
2039	6,589	1,183	7,772	5,060	115	12,947
2040	6,654	1,200	7,854	5,173	116	13,143

Table 0-48 Projected Commercial Marine Air Toxic Emission Reductions (short tons)

HAP	2010	2015	2020	2030
BENZENE	0	45	162	371
FORMALDEHYDE	4	328	1,190	2,730
ACETALDEHYDE	2	163	591	1,357
1,3-BUTADIENE	0	0	2	4
ACROLEIN	0	6	23	53
NAPHTHALENE	0	3	10	24
POM	0	0	2	5

3.2 Recreational Marine Diesel Engines

This section describes the methodology and presents the resulting baseline and controlled inventories for recreational marine (pleasure craft) diesel propulsion engines, including the projected emission reductions from the proposed rule. These engines are already subject to existing emission control standards, so the baseline inventories presented here account for those existing standards. Emissions from any diesel auxiliary engines used on recreational marine vessels are covered above in the section on engines less than 37 kW or the section on Category 1 engines, if they are over 37 kW.

3.2.1 General Methodology

The general methodology for calculating recreational marine diesel engine inventories for HC, CO, NO_x, PM_{10}, SO_2, VOC, $PM_{2.5}$, and fuel consumption uses the EPA NONROAD2005 model with inputs modified to reflect the proposed standards as well as updated baseline data.[13] Air toxic inventories are not generated by the NONROAD model, so those are calculated separately. NONROAD separates recreational diesel engines into two basic categories: inboard and outboard engines. NONROAD also subdivides these by power range. There are relatively few outboard diesels, and they are all in the 25 - 40 hp range.

The actual calculation methodology used by the NONROAD model is the same as described above in section 3.1.1 for all other marine diesel engines. Following is a summary of that.

Equation 5 $$I = N*P*L*A*EF$$

where each term is defined as follows:

I = the emission inventory (gram/year)
N = engine population (units)
P = average rated power (kW)
L = load factor (average fraction of rated power used during operation; unitless)

A = engine activity (operating hours/year)
EF = emission factor (gram/kW-hr)

Emissions are then converted and reported as short tons/year. In NONROAD the inputs are expressed in terms of horsepower (hp) instead of kW, and gram/bhp-hr instead of gram/kW-hr.

Three variables are used to project emissions over time: the engine population growth, the engine median life/scrappage, and the relative emissions deterioration rate.

Engine Population Growth. Unlike the commercial marine methodology which uses a compound population growth rate, the NONROAD model uses a linear growth assumption for recreational diesel engines, which is represented by a set of growth indexes that provide a ratio of estimation year population relative to the base year population.[14] The growth used for recreational diesel engines is 3.3 percent per year relative to a 1996 base year; i.e., each year the population grows by the same number of engines, and that number is 3.3 percent of the 1996 population.

Engine Median Life (years) and Scrappage. The engine median life defines the length of time engines remain in service. Engines persist in the population over two median lives; during the first median life, 50 percent of the engines are scrapped, and over the second, the remaining 50 percent of the engines are scrapped. Engine median lives also vary by category. The median life of both inboard and outboard engines is assumed to be 20 years, but due to the different activities used for these two categories (200 and 150 hours/year, respectively), the corresponding median life inputs for the model are 1400 and 1050 hours at full load. The age distribution is defined by the median life and the scrappage algorithm. The same basic scrappage algorithm is used for recreational and commercial marine diesel engines.[1]

Relative Deterioration Rate (percent increase in emission factor/percent median life expended). A deterioration factor can be applied to the emission factor to account for in-use deterioration. The deterioration factor varies by age and is calculated as:

Equation 6 $$DF = 1 + A*(age/ML)$$

where each term is defined as follows:
DF = the deterioration factor for a given pollutant at a given age
A = the relative deterioration rate for a given pollutant (percent increase in emission factor/percent useful life expended)
age = the age of a specific model year group of engines in the simulation year (years)
ML = the median life of the given model year cohort (years)

A given model year cohort is represented as a fraction of the entire population. In the NONROAD model the deterioration factor adjusts the emission factor for engines in a given model year cohort in relation to the proportion of median life expended.[2] Deterioration is linear over one median life. Following the first median life, the deteriorated emission factor is held constant over the remaining life for engines in the cohort.

Sulfur Adjustment for PM Emissions. For Tier 2 and prior engines, a sulfate adjustment is added to the PM emissions to account for differences in fuel sulfur content between the certification fuel and the episodic (calendar year) fuel, using the following equation:

Equation 3 $$S_{PM\ adj} = FC * 7.1 * 0.02247 * 224/32 * (soxdsl - soxbas) * 1/2000$$

where each term is defined as follows:
$S_{PM\ adj}$ = PM sulfate adjustment (tons)
FC = fuel consumption (gallons)
7.1 = fuel density (lb/gal)
0.02247 = fraction of fuel sulfur converted to sulfate
224/32 = grams PM sulfate/grams PM sulfur
soxdsl = episodic fuel sulfur weight fraction (varies by calendar year)
soxbas = certification fuel sulfur weight fraction
2000 = conversion from lb to ton

For engines prior to Tier 2 the base fuel sulfur (soxbas) is assumed to be 3300 ppm. For Tier 2 engines less than or equal to 50 hp (37 kW) it is set at 2000 ppm, as described in the Clean Air Nonroad Diesel Rule.[4], since these smaller engines are subject to the same standards as land-based diesel engines. For Tier 2 engines greater than 50 hp (37 kW) it is set at 350 ppm, based on the most recent certification data for these engines. For Tier 3 and later engines, no sulfur adjustment is applied. These engines will be certified to a fuel sulfur level at or lower than the episodic fuel sulfur levels expected when these engines are introduced.

The calendar year fuel sulfur levels (soxdsl) were taken from the Clean Air Nonroad Diesel Rule.[4]

Estimation of air toxic emissions. The air toxic baseline emission inventories for this proposal are based on information developed for EPA's Mobile Source Air Toxics (MSAT) final rulemaking.[5] That rule calculated air toxic emission inventories for all nonroad engines. The gaseous air toxics are correlated to VOC emissions, while POM is correlated to PM_{10} emissions. To calculate the air toxics emission inventories and reductions for this proposal, the percent reductions in VOC and PM_{10} emissions will be applied to the baseline gaseous and POM air toxic inventories, respectively.

3.2.2 Baseline (Pre-Control) Inventory Development

3.2.2.1 Baseline Inventory Inputs

This section describes the NONROAD model inputs that were used to generate the baseline emission inventories for recreational marine diesel engines.

Table 0-49 and Table 0-50 list the base engine populations, average hp by power range, annual activity, load factor, and median life. These also apply to the control case, and are unchanged from the default inputs in the NONROAD model.

Table 0-49 Recreational Marine Diesel Modeling Inputs

NONROAD MODEL INPUT	RECREATIONAL MARINE DIESEL	
	INBOARD	OUTBOARD
POPULATION (year 2000)	291,387*	9,819
HP AVERAGE	*	32.25
ACTIVITY HRS/YEAR	200	150
LOAD FACTOR	0.35	0.35
MEDIAN LIFE (hrs at full load)	1400	1050
MEDIAN LIFE (years)	20	20
* See TABLE 0-50 for breakout by individual power ranges.		

Table 0-50 Recreational Marine Inboard Diesel Population

POWER RANGE	DIESEL REC MARINE INBOARD	
MIN < HP <= MAX	HP AVG	POPULATION
0 - 11	9.736	9,126
11 - 16	14.92	4,478
16 - 25	21.41	9,908
25 - 40	31.2	5,421
40 - 50	42.4	1,002
50 - 75	56.19	8,784
75 - 100	94.22	7,397
100 - 175	144.9	60,632
175 - 300	223.1	99,703
300 - 600	387.1	73,546
600 - 750	677	2,902
750 - 1000	876.5	5,502
1000 - 1200	1154	448
1200 - 2000	1369	1,573
2000 - 3000	2294	964
TOTAL		291,387

The baseline emission factors are given in Table 0-51 and Table 0-52. "Zero Hour" emission factors represent the emissions from new engines that have been broken in, but before any significant deterioration occurs. The Deterioration Factor is used to calculate how emissions change as the engine and emission control system deteriorate over time, as explained above in Equation 2. Engines under 50 hp are subject to EPA nonroad diesel regulations that have established two tiers of emission standards.[12] Tier 1 phased in from 1999-2000, depending on the hp category, and Tier 2 phased in from 2004-2005. Engines above 50 hp are subject to separate standards (shown in the Tier 2 column) that take effect in 2008-2012, depending on hp category. The “Base” entries in the tables refer to emissions from pre-controlled engines. All these emission factors are used for both inboard and outboard diesel engines, although the outboards are all under 50 hp.

The emission factors for the base and Tier 1 technology types are unchanged from what has been in the NONROAD model.[2] Tier 2 emission factors were updated from those in the NONROAD model using all the nonroad engine certification data available in mid-2006. The deterioration factors by pollutant and technology type are also given in the tables above, and they are unchanged from what has been in the NONROAD model.[2]

The certification fuel sulfur levels are 3300ppm for the base and Tier 1 technology type and 350ppm for Tier 2. Brake Specific Fuel Consumption (BSFC) values in the NONROAD model are 0.408 lb/hp-hr for all hp categories.[2]

Table 0-51 Baseline PM_{10} and NO_x Zero Hour Emission Factors and Deterioration Factors for Recreational Marine Diesel Engines

HP RANGE	PM_{10} G/HP-HR			NO_X G/HP-HR		
	BASE	TIER1	TIER2	BASE	TIER1	TIER2
0-11	1.00	0.45	0.38	10.00	5.23	4.39
11-16	0.90	0.27	0.19	8.50	4.44	3.63
16-25	0.90	0.27	0.19	8.50	4.44	3.63
25-50	0.80	0.34	0.23	6.90	4.73	3.71
50-75	0.16	0.16	0.13	6.67	6.67	3.82
75-100	0.16	0.16	0.13	6.67	6.67	3.82
100-175	0.16	0.16	0.13	6.67	6.67	3.82
175-300	0.16	0.16	0.090	6.67	6.67	4.46
300-600	0.16	0.16	0.082	6.67	6.67	4.42
600-750	0.16	0.16	0.082	6.67	6.67	4.42
750-1200	0.16	0.16	0.082	6.67	6.67	4.42
>1200	0.16	0.16	0.082	6.67	6.67	4.42
DF ("A")	0.473	0.473	0.473	0.024	0.024	0.009

Table 0-52 Baseline HC and CO Zero Hour Emission Factors and Deterioration Factors for Recreational Marine Diesel Engines

HP RANGE	HC G/HP-HR			CO G/HP-HR		
	BASE	TIER1	TIER2	BASE	TIER1	TIER2
0-11	1.50	0.76	0.68	5.00	4.11	4.11
11-16	1.70	0.44	0.21	5.00	2.16	2.16
16-25	1.70	0.44	0.21	5.00	2.16	2.16
25-50	1.80	0.28	0.54	5.00	1.53	1.53
50-75	0.22	0.22	0.20	0.95	0.95	0.95
75-100	0.22	0.22	0.20	0.95	0.95	0.95
100-175	0.22	0.22	0.20	0.95	0.95	0.95
175-300	0.22	0.22	0.25	0.95	0.95	0.95
300-600	0.22	0.22	0.33	0.95	0.95	0.95
600-750	0.22	0.22	0.33	0.95	0.95	0.95
750-1200	0.22	0.22	0.33	0.95	0.95	0.95
>1200	0.22	0.22	0.33	0.95	0.95	0.95
DF ("A")	0.047	0.047	0.034	0.185	0.101	0.101

3.2.2.2 Recreational Marine Diesel Baseline Inventory

3.2.2.2.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

Table 0-53 shows the baseline 50-state emission inventories for recreational marine diesel engines (inboard and outboard combined) resulting from the baseline model inputs presented above.

3.2.2.2.2 Air Toxics Emissions

The baseline air toxics inventories for recreational marine diesel engines were taken from the final MSAT rule[5] and are summarized in Table 0-54. Inventories are provided for calendar year 1999, and are projected for 2010, 2015, 2020, and 2030.

Table 0-53 Baseline (50-State) Emissions for Recreational Marine Diesel Engines (short tons)

YEAR	PM_{10}	PM2.5	NO_X	VOC	HC	CO	SO_2
2002	1,130	1,096	40,437	1,540	1,462	6,467	5,145
2003	1,161	1,126	41,572	1,578	1,499	6,642	5,290
2004	1,192	1,156	42,704	1,618	1,536	6,816	5,436
2005	1,223	1,186	43,835	1,656	1,573	6,989	5,582
2006	1,247	1,210	44,089	1,720	1,633	7,161	5,621
2007	1,054	1,023	44,307	1,783	1,693	7,331	2,967
2008	915	888	44,513	1,846	1,753	7,499	993
2009	937	909	44,648	1,912	1,816	7,665	1,017
2010	935	907	44,772	1,979	1,879	7,829	764
2011	938	910	44,880	2,045	1,942	7,991	578
2012	934	906	44,977	2,112	2,006	8,150	311
2013	935	907	45,064	2,179	2,069	8,308	113
2014	952	924	45,139	2,246	2,133	8,464	136
2015	969	940	45,208	2,313	2,196	8,618	150
2016	984	954	45,270	2,380	2,260	8,771	153
2017	998	968	45,327	2,448	2,325	8,922	156
2018	1,011	981	45,378	2,516	2,389	9,073	156
2019	1,024	994	45,427	2,584	2,454	9,223	159
2020	1,037	1,006	45,477	2,653	2,520	9,374	162
2021	1,050	1,019	45,531	2,723	2,586	9,525	165
2022	1,063	1,031	45,586	2,793	2,652	9,675	168
2023	1,075	1,043	45,649	2,862	2,718	9,825	171
2024	1,087	1,054	45,729	2,932	2,784	9,975	174
2025	1,099	1,066	45,842	3,000	2,849	10,124	177
2026	1,112	1,079	46,114	3,064	2,910	10,279	180
2027	1,127	1,093	46,549	3,124	2,967	10,439	183
2028	1,143	1,108	47,030	3,184	3,023	10,601	186
2029	1,159	1,124	47,551	3,242	3,079	10,765	189
2030	1,175	1,140	48,102	3,299	3,133	10,930	192
2031	1,192	1,156	48,671	3,356	3,187	11,095	195
2032	1,208	1,172	49,257	3,412	3,240	11,262	199
2033	1,226	1,189	49,861	3,468	3,294	11,429	202
2034	1,243	1,205	50,477	3,524	3,346	11,596	205
2035	1,260	1,222	51,106	3,579	3,399	11,765	208
2036	1,278	1,239	51,748	3,634	3,451	11,933	211
2037	1,295	1,256	52,399	3,689	3,503	12,102	214
2038	1,313	1,274	53,062	3,744	3,555	12,272	217
2039	1,331	1,291	53,735	3,798	3,607	12,442	220
2040	1,349	1,308	54,417	3,852	3,659	12,613	223

Table 0-54 Baseline Air Toxics Emissions for Recreational Marine Diesel Engines (short tons)

HAP	1999	2010	2015	2020	2030
BENZENE	30	34	34	34	35
FORMALDEHYDE	176	199	197	195	201
ACETALDEHYDE	79	89	88	87	90
1,3-BUTADIENE	3	3	3	3	3
ACROLEIN	5	5	5	5	5
NAPHTHALENE	0	0	0	0	0
POM	1	0	0	0	0

3.2.3 Control Inventory Development

3.2.3.1 Control Scenario(s) Modeled

Table 0-55 shows the control case exhaust emission standards that were modeled for recreational marine diesel engines.

Table 0-55 Modeled Standards (g/hp-hr) for Recreational Marine Diesel Engines

HP RANGE	TIER 3			TIER 4		
	YEAR	NO_X+HC	PM	YEAR	NO_X	PM
0-25	2009	5.6	0.30		NO TIER 4 STANDARDS	
25-100	2009	5.6	0.22			
	2014	3.5	0.22			
100-175	2012	4.3	0.11			
175-300	2013	4.3	0.10			
300-750	2014	4.3	0.09			
750-1200	2013	4.3	0.09			
1200-2680	2012	4.0	0.09			
>2680	2012	4.0	0.09	2016	1.27	0.03

3.2.3.2 Control Inventory Inputs

Table 0-56 shows the NONROAD model emission factor inputs that were used to generate the control case emission inventories for recreational marine diesel engines. These emission factors were applied to engines beginning with the model years shown in Table 0-55. No sulfur adjustment is applied to the Tier 3 or Tier 4 PM calculations, since these engines will be certified to a fuel sulfur level at or lower than the episodic fuel sulfur levels expected when these engines are introduced. The Tier 4 modeled emission factors are identical to the Tier 4 emission factors used for Category 1 standard power density propulsion engines. However, the NONROAD model does not have a hp bin corresponding to greater than 2000 kW (2680 hp), so the 2000-3000 hp bin was used to model the effects of the Tier 4 standard.

All other modeling inputs are the same as shown above for the base case inventory development. Table 0-49 and Table 0-50 list the base engine populations, average hp by power range, annual activity, load factor, and median life. These are unchanged from the default inputs in the NONROAD model.

Table 0-56 Control Emission Factors for Recreational Marine Diesel Engines

HP RANGE	TIER 3 EMISSION FACTORS G/HP-HR				TIER 4 EMISSION FACTORS G/HP-HR			
	PM_{10}	NO_X	HC	CO	PM_{10}	NO_X	HC	CO
0-11	0.24	4.39	0.43	4.11	NO TIER 4 STANDARDS			
11-16	0.19	3.63	0.21	2.16				
16-25	0.19	3.63	0.21	2.16				
25-50	0.18	3.71	0.41	1.53				
	0.18	2.32	0.41	1.53				
50-75	0.13	3.82	0.20	0.95				
	0.13	2.39	0.20	0.95				
75-100	0.13	3.82	0.20	0.95				
	0.13	2.39	0.20	0.95				
100-175	0.088	3.34	0.13	0.95				
175-300	0.080	3.90	0.22	0.95				
300-600	0.072	3.98	0.29	0.95				
600-750	0.072	3.98	0.29	0.95				
750-1200	0.072	3.70	0.29	0.95				
1200-2000	0.072	3.70	0.29	0.95				
>2000	0.072	3.70	0.29	0.95	0.022	0.97	0.03	0.95
DF ("A")	0.473	0.009	0.034	0.101	0.473	0.009	0.034	0.101

3.2.3.3 Recreational Marine Diesel Control Inventory

3.2.3.3.1 PM_{10}, $PM_{2.5}$, NO_x, VOC, CO, and SO_2 Emissions

The control case 50-state emission inventories for recreational marine diesel engines (inboard and outboard combined) resulting from the control case model inputs presented above are shown in Table 0-57.

3.2.3.3.2 Air Toxics Emissions

The control case air toxics inventories for recreational marine diesel engines are provided in Table 0-58. Gaseous air toxics and POM are reduced proportionately to VOC and $PM_{2.5}$, respectively.

Table 0-57 Control Case (50-State) Emissions for Recreational Marine Diesel Engines (short tons)

YEAR	PM$_{10}$	PM$_{2.5}$	NO$_X$	VOC	HC	CO	SO$_2$
2002	1,130	1,096	40,437	1,540	1,462	6,467	5,145
2003	1,161	1,126	41,572	1,578	1,499	6,642	5,290
2004	1,192	1,156	42,704	1,618	1,536	6,816	5,436
2005	1,223	1,186	43,835	1,656	1,573	6,989	5,582
2006	1,247	1,210	44,089	1,720	1,633	7,161	5,621
2007	1,054	1,023	44,307	1,783	1,693	7,331	2,967
2008	915	888	44,513	1,846	1,753	7,499	993
2009	937	909	44,648	1,912	1,816	7,665	1,017
2010	935	907	44,772	1,978	1,878	7,829	764
2011	938	910	44,880	2,044	1,941	7,991	578
2012	931	903	44,931	2,104	1,998	8,150	311
2013	930	902	44,864	2,159	2,051	8,308	113
2014	944	916	44,681	2,206	2,095	8,464	136
2015	957	928	44,490	2,252	2,139	8,618	150
2016	967	938	44,248	2,294	2,179	8,771	153
2017	976	947	43,998	2,337	2,219	8,922	156
2018	985	955	43,742	2,379	2,259	9,073	156
2019	993	963	43,479	2,421	2,300	9,223	159
2020	1,001	971	43,218	2,465	2,341	9,374	162
2021	1,008	978	42,957	2,508	2,382	9,525	165
2022	1,015	985	42,697	2,552	2,423	9,675	168
2023	1,022	991	42,443	2,595	2,465	9,825	171
2024	1,028	997	42,206	2,638	2,505	9,975	174
2025	1,033	1,002	42,001	2,680	2,545	10,124	177
2026	1,041	1,009	41,955	2,717	2,581	10,279	180
2027	1,049	1,018	42,072	2,751	2,613	10,439	183
2028	1,058	1,026	42,237	2,784	2,644	10,601	186
2029	1,068	1,036	42,443	2,816	2,674	10,765	189
2030	1,077	1,045	42,683	2,847	2,704	10,930	193
2031	1,088	1,055	42,946	2,879	2,734	11,095	196
2032	1,098	1,066	43,241	2,911	2,765	11,262	199
2033	1,110	1,077	43,584	2,946	2,797	11,429	202
2034	1,123	1,089	43,979	2,983	2,832	11,596	205
2035	1,136	1,102	44,412	3,021	2,869	11,765	208
2036	1,150	1,115	44,875	3,061	2,907	11,933	211
2037	1,164	1,129	45,359	3,102	2,946	12,102	214
2038	1,179	1,143	45,864	3,143	2,985	12,272	217
2039	1,193	1,158	46,382	3,185	3,025	12,442	220
2040	1,208	1,172	46,915	3,227	3,064	12,613	223

Table 0-58 Control Case Air Toxic Emissions for Recreational Marine Diesel Engines (short tons)

HAP	2010	2015	2020	2030
BENZENE	34	33	31	30
FORMALDEHYDE	198	192	181	174
ACETALDEHYDE	89	86	81	78
1,3-BUTADIENE	3	3	3	3
ACROLEIN	5	5	5	4
NAPHTHALENE	0	0	0	0
POM	0	0	0	0

3.2.4 Projected Recreational Marine Emission Reductions of Proposal

The $PM_{2.5}$, NO_x, and VOC emission reductions by calendar year are shown in Table 0-59. The air toxic emission reductions by pollutant and calendar year are given in Table 0-60.

Table 0-59 Projected Recreational Marine Emission Reductions (short tons)

YEAR	$PM_{2.5}$	NO_X	VOC
2008	0	0	0
2009	0	0	1
2010	0	0	1
2011	1	0	2
2012	3	47	8
2013	5	200	20
2014	8	458	40
2015	12	718	61
2016	16	1,022	86
2017	21	1,328	111
2018	25	1,637	137
2019	30	1,947	163
2020	35	2,260	188
2021	41	2,574	215
2022	46	2,889	241
2023	52	3,206	267
2024	58	3,524	294
2025	63	3,842	320
2026	70	4,160	347
2027	76	4,477	373
2028	82	4,793	400
2029	88	5,108	426
2030	95	5,419	452
2031	101	5,725	477
2032	107	6,016	501
2033	112	6,277	523
2034	116	6,498	541
2035	120	6,693	558
2036	124	6,873	573
2037	127	7,039	587
2038	130	7,199	600
2039	133	7,353	613
2040	136	7,502	626

Table 0-60 Projected Air Toxic Reductions from Recreational Marine Diesel Engines (short tons)

HAP	2010	2015	2020	2030
BENZENE	0	1	2	5
FORMALDEHYDE	0	5	14	28
ACETALDEHYDE	0	2	6	12
1,3-BUTADIENE	0	0	0	0
ACROLEIN	0	0	0	1
NAPHTHALENE	0	0	0	0
POM	0	0	0	0

3.3 Locomotives

3.3.1 General Methodology

Given the quality of the data available, it was possible to develop more detailed estimates of fleet composition and emission rates. Locomotive emissions were calculated based on estimated current and projected fuel consumption rates. Emissions were calculated separately for the following locomotive categories:

- Large Railroad Line-Haul Locomotives
- Large Railroad Switching (including Class II/III Switch railroads owned by Class I railroads)
- Other Line-Haul Locomotives (i.e., local and regional railroads)
- Other Switch/Terminal Locomotives
- Passenger/Commuter Locomotives

We used the following approach for all categories, except for the small railroads (see 3.3.2.3). For each calendar year, locomotives are tracked separately by model year and then the activity is summed (in terms of work, fuel, and emissions) for all model years in the fleet. Seven basic steps were used to determine emissions in any calendar year:

1. Start with the fleet from the previous calendar year.
2. Determine which model years would be due to be remanufactured or scrapped.
3. Update the fleet to remove locomotives that would be scrapped.
4. Determine the amount of work that would be done by the remaining locomotives from the previous year's fleet.

5. Determine the number of freshly manufactured locomotives that would be purchased, and add them to the fleet.

6. Determine the total amount of work that would be done by all the locomotives in the fleet.

7. Determine total emissions from the work and brake-specific emission factors.

3.3.1.1 Base Fleet

As is described later, the base fleet was estimated for 2005 from a variety of industry sources. A new base fleet is calculated for each subsequent calendar year based on the scrappage rates and sales. The base fleet is a sum of multiple model years that are described by the number of locomotives in the fleet, the average work that has been accumulated since the last rebuild (in megawatt-hours or MW-hr), the average horsepower, and the Tier of standards to which they are certified.

3.3.1.2 Useful Life

In this analysis, all locomotives are assumed to be either remanufactured or scrapped when they reach or exceed their useful life. The useful life in MW-hrs is set equal to the rated horsepower of the locomotive multiplied by 7.5. Thus a 4000 horsepower locomotive would have a useful life of 30,000 MW-hrs. Annual accumulation of MW-hrs is projected based on the assumed rated hp of the locomotive and the relative use rate (which is a function of locomotive age). At the end of this second step, the projected fleet is adjusted to reflect a year's worth of use beyond the previous base fleet.

3.3.1.3 Scrappage

For each future calendar year, there will generally be some locomotive model years that will be projected to have reached the end of their current useful life. For example, we estimate that there will be 243 line-haul freight locomotives in use in 2010 that:

- Were originally manufactured in model year 1986.

- Will be accumulating about 2000 MW-hrs per year.

- Will reach the end of their useful lives during 2011.

According to our scrappage curve, we estimate that 15 of these locomotives will be scrapped in 2011. The remaining 228 are projected to be remanufactured. We perform this analysis for each model year, then update that fleet to remove locomotives that would be scrapped and change the emission levels for locomotives that are remanufactured to new standards.

3.3.1.4 Work Done by Old Fleet

Once the existing fleet is adjusted for each new calendar year, we determine the amount of work that would be done by the remaining locomotives from the previous year’s fleet. First we calculate the amount of work done by each model year's fleet as follows:

Equation 7 $$W_i = H*LF*N_i*P_i*RUF_i$$

W_i = Combined annual work output for all locomotives remaining in the fleet that were originally manufactured in model year i.

H = Number of hours per year that a newly manufactured locomotive is projected to be used (approximately 4000 to 5000 hrs/yr).

L = Typical average load factor.

N_i = Number of locomotives remaining in the fleet that were originally manufactured in model year i.

P_i = Average rated power of locomotives remaining in the fleet that were originally manufactured in model year i.

RUF_i = Relative use factor for locomotives remaining in the fleet that were originally manufactured in model year i.

The total work done by the remaining fleet (W_r) is calculated by summing the work done by each model year (W_i).

3.3.1.5 New Sales

Sales of newly manufactured locomotives are projected for each calendar year after the remaining fleet has been analyzed. These newly manufactured locomotives are added to the remaining locomotives to comprise a new total fleet. The number is calculated based on the amount of fuel that is projected to be used in that calendar year:

Equation 8 $$\text{New Sales} = (\text{Total Fuel}/\text{BSFC} - W_r)/H/LF/P$$

Where BSFC is the estimated brake specific fuel consumption rate (Gal/MW-hr)

3.3.1.6 Total Work

The total amount of work that would be done by all the locomotives in the fleet is calculated for each calendar year by summing the work projected to be done by the newly manufactured locomotives and the work projected to be done by the remaining locomotives. The total work is calculated separately for each tier of locomotives.

3.3.1.7 Emissions

Emissions are determined from the work calculated in section 3.3.1.6 (converted to hp-hrs) and brake-specific emission factors:

Equation 9 Total emissions = Total Work * Emission factor

The emission factors used are the estimated average in-use emissions for each tier of standards, which are shown in Table 0-61 and Table 0-62. They take into account deterioration of emissions throughout the useful life, production variations, and the compliance margins that manufacturers incorporate into their designs. For this analysis, we are generally assuming that average in-use emission levels will be 10 percent below the applicable standards.

Table 0-61 Baseline Line-Haul Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.32	0.48	13.0	1.28
TIER 0	0.32	0.48	8.60	1.28
TIER 1	0.32	0.47	6.70	1.28
TIER2	0.18	0.26	4.95	1.28

Table 0-62 Baseline Switch Emission Factors (g/bhp-hr)

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.44	1.01	17.4	1.83
TIER 0	0.44	1.01	12.6	1.83
TIER 1	0.43	1.01	9.9	1.83
TIER 2	0.19	0.51	7.3	1.83

These PM_{10} emission factors reflect the emission rates expected from locomotives operating on current in-use fuel with sulfur levels at 3000 ppm. The emission inventories described in this chapter, however, account for the reductions in sulfate particulate expected to result from using lower sulfur fuels after 2007. We estimate that the PM_{10} emission rate for locomotives operating on nominally 500 ppm sulfur fuel will be 0.029 g/bhp-hr lower than the PM_{10} emission rate for locomotives operating on 3000 ppm sulfur fuel. Similarly we estimate that the PM_{10} emission rate for locomotives operating on nominally 15 ppm sulfur fuel will be 0.033 g/bhp-hr lower than the PM_{10} emission rate for locomotives operating on 3000 ppm sulfur fuel.

To estimate VOC emissions, an adjustment factor of 1.053 is applied to the HC output. Similarly, to estimate $PM_{2.5}$ emissions, an adjustment factor of 0.97 is applied to the PM_{10} output. These adjustment factors are the same as those used for marine engines.

3.3.2 Baseline (Pre-Control) Inventory Development

In developing the baseline inventory, we collected fuel consumption estimates from the regulated industries, including publicly available estimates for Class I and commuter railroads. We used the same estimated average in-use emission factors and load factors as we used in the previous rulemaking.

We are using a projection by the Energy Information Administration (EIA) that locomotive fuel consumption will grow 1.6 percent annually.[8] We are assuming that this fuel growth applies equally across all categories of locomotives and is directly proportional to engine work performed by the fleet.

Table 0-63 Summary of Locomotive Emission Analysis Inputs

	Large Line-Haul	Large Switch	Small Line-Haul	Small Switch	Passenger/ Commuter
2005 FUEL CONSUMPTION (GAL/YR)	3.910 BILLION	310 MILLION	105 MILLION	39 MILLION	142 MILLION
HOURS USED PER YEAR WHEN NEW	4350	4450	NA	NA	3900
YEARS AFTER WHICH USAGE BEGINS TO DECLINE	8	50	NA	NA	20
HOURS PER YEAR AT END OF LIFE	1740 @ 40 YRS	3115 @ 70 YRS	NA	NA	2340@30YRS
AGE AFTER WHICH SCRAPPAGE BEGINS	20	50	NA	NA	20
AGE AFTER WHICH NO LOCOMOTIVES REMAIN IN FLEET	40	70	NA	NA	30
LOAD FACTOR (AVG HP/RATED HP)	0.275	0.100	0.275	0.100	0.275
AVG HP/GAL	20.8	15.2	18.2	15.2	20.8

3.3.2.1 Large Line-Haul

The large line-haul category includes line-haul freight locomotives that are fully subject to the standards being proposed. Locomotives that are owned and operated by railroads that qualify as small businesses are addressed separately, as described in 3.3.2.3. The large line-haul analysis is based primarily on data collected for Class I railroads. However, as described in 3.3.2.3, the total fuel includes one-third of the estimated Class II and Class III fuel use to account for those Class II and III railroads that do not qualify as small businesses. The estimate of current Class I total fuel use came from the AAR Railroad Facts booklet. This was reduced by 7 percent to reflect fuel used in switching rather than line-haul operation. The fleet composition for all large railroads was estimated based on a contractor analysis. The contractor estimated that this fleet included 19,757 locomotives with more than 2500 hp. (Locomotives with 2500 hp or less were assumed to be used primarily in switching operations.) Usage and scrappage patterns were developed to fit the fuel use and fleet composition data. The average in-use load factor was assumed to be the same as the load factor for a typical line-haul duty cycle test.

3.3.2.2 Large Switch

We generally used the same approach to calculate switch emissions as we used to calculate line-haul emissions, but we used different inputs. We also made one change to the analysis of future sales. We assumed that the majority of growth in switching activity will be achieved by using switch locomotives more rather than by adding new switch locomotives to the fleet. More specifically, we assumed that 1.2 percent of the annual 1.6 percent growth in activity will be achieved by using the existing switchers more, while only 0.4 percent of the growth will be achieved by increasing the number of switchers in the fleet.

As shown in Table 0-63, we believe that switch locomotives tend to last longer in the fleet and have a lower in-use load factor than line-haul locomotives. Thus the average age of switch locomotives is much older then for line-haul. We also estimate that switching operation will use approximately seven percent of total large railroad fuel, and will grow at the same rate as line-haul operation. The switch fleet composition for all large railroads was estimated based on the same contractor analysis used for the line-haul fleet. The contractor estimated that this fleet included 5206 locomotives with 2500 hp or less. This included 1645 locomotives with 2250 to 2500 hp. While we recognize that some of these locomotives will be used in branch service[d], for this analysis they are assumed to be used primarily in switching operations.

3.3.2.3 Small Railroads

We used a simplified approach for small railroads (that is railroads that are not required to retrofit their locomotive with new emission controls because they qualify as "small railroads" under the regulatory definition). We assume that these small railroads are unlike the larger railroads in the following ways:

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[d] Branch service includes short-haul operations that would be considered intermediate to intercity line-haul service and switch service.

- They do not purchase newly manufactured locomotive.
- They use their locomotives at a constant rate.
- They replace their existing locomotives at a constant rate of 3 percent per year.

For this analysis, we considered small railroad activity in the same two categories as the larger railroads: line-haul and switch. For small line-haul operations, we are projecting that railroads will scrap and replace their oldest locomotives with 25 year-old locomotives purchased from the larger railroads. Thus the inventory analysis has these railroads obtaining Tier 1 locomotives starting in 2026, and Tier 2 locomotives in 2030. For small switch operations, the railroads are projected to replace their scrapped locomotives with only uncontrolled or Tier 0 locomotives purchased from the larger railroads. This analysis runs only through 2040 and we consider it unlikely that any significant number of Tier 1 or later switch locomotives will be available for small railroads before 2040.

The analysis of small railroads is based on the survey information provided by the American Shortline Railroad Association for Class II and Class III railroads. These results had to be adjusted upward to correct for a response rate of approximately 85 percent. We also had to adjust these estimates because not all Class II and Class III railroads qualify as small railroads under the regulations. We estimate that one-third of these railroads are owned by Class I railroads or other large businesses. Finally, we estimated the fraction small railroad activity should be characterized as line-haul service versus switching service. We estimate that Class II railroads use 7 percent of their fuel in switching service (the same as Class I railroads), but that Class III railroads use 50 percent of their fuel in switching service. When combined, these factors result in our estimate that small railroads used a total of 105 million gallons of diesel fuel in line-haul service in 2005, and 39 million gallons of diesel fuel in switching service, as shown in Table 3-64.

Table 0-64 Distribution of annual fuel consumption by Class II and Class III railroads (million gallons per year)

	Amount of fuel used by railroads that qualify as small railroads		Fuel used by other Class II and Class III railroads	
	LINE-HAUL	SWITCH	LINE-HAUL	SWITCH
CLASS II	71.5	5.4	35.7	2.7
CLASS III	33.7	33.7	16.8	16.8

3.3.2.4 Passenger/Commuter

We used the same approach to calculate passenger and commuter emissions as we used to calculate large line-haul emissions, but we used different inputs. As shown in the table, we believe that passenger/commuter locomotives tend to have an average age that is slightly newer then for line-haul. We used estimates from AMTRAK and APTA for current fuel consumption rates, and project that these will grow at the same rate as line-haul operation.

3.3.2.5 Locomotive Baseline Inventory Summary

The baseline locomotive inventory is shown separately for PM_{10}, $PM_{2.5}$, NO_x, VOC, HC, CO, and SO_2 in Table 0-65 through Table 0-71.

The baseline air toxics inventories for locomotives were taken from the MSAT rule and are provided in Table 0-72. Inventories are provided for calendar years 1999, 2010, 2015, 2020, and 2030.

Table 0-65 Baseline (50-State) PM_{10} Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	27,919	2,270	935	1,023	32,147
2007	27,873	2,295	950	1,011	32,129
2008	25,078	2,162	883	901	29,023
2009	24,965	2,185	897	888	28,934
2010	24,831	2,208	911	874	28,824
2011	24,686	2,232	926	859	28,703
2012	24,536	2,256	940	845	28,577
2013	24,015	2,258	944	817	28,033
2014	23,874	2,282	959	802	27,916
2015	23,724	2,306	974	787	27,791
2016	23,561	2,330	990	771	27,653
2017	23,398	2,355	1,006	756	27,515
2018	23,240	2,380	1,022	741	27,383
2019	23,081	2,405	1,038	726	27,251
2020	22,918	2,431	1,055	711	27,114
2021	22,750	2,457	1,071	696	26,974
2022	22,579	2,483	1,088	681	26,831
2023	22,407	2,490	1,106	666	26,668
2024	22,244	2,489	1,124	651	26,508
2025	22,080	2,483	1,141	636	26,340
2026	21,944	2,472	1,160	624	26,200
2027	21,836	2,456	1,178	614	26,084
2028	21,755	2,434	1,197	607	25,993
2029	21,703	2,410	1,216	602	25,931
2030	21,685	2,380	1,223	598	25,886
2031	21,696	2,343	1,230	597	25,866
2032	21,735	2,301	1,237	598	25,871
2033	21,800	2,257	1,243	600	25,901
2034	21,894	2,209	1,250	603	25,957
2035	22,023	2,161	1,256	608	26,049
2036	22,187	2,113	1,263	613	26,176
2037	22,378	2,066	1,269	618	26,331
2038	22,597	2,018	1,275	623	26,513
2039	22,846	1,971	1,281	628	26,726
2040	23,126	1,924	1,287	633	26,969

Table 0-66 Baseline (50-State) $PM_{2.5}$ Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	27,082	2,202	907	992	31,183
2007	27,037	2,226	922	981	31,166
2008	24,325	2,097	856	874	28,153
2009	24,216	2,120	870	861	28,066
2010	24,086	2,142	884	847	27,959
2011	23,946	2,165	898	833	27,842
2012	23,800	2,188	912	819	27,720
2013	23,294	2,190	916	792	27,192
2014	23,157	2,213	930	778	27,079
2015	23,012	2,237	945	763	26,957
2016	22,854	2,260	960	748	26,823
2017	22,696	2,284	975	734	26,690
2018	22,542	2,309	991	719	26,561
2019	22,389	2,333	1,007	704	26,433
2020	22,230	2,358	1,023	690	26,301
2021	22,067	2,383	1,039	675	26,165
2022	21,902	2,409	1,056	660	26,026
2023	21,734	2,415	1,073	646	25,868
2024	21,577	2,415	1,090	631	25,713
2025	21,417	2,408	1,107	617	25,550
2026	21,286	2,398	1,125	605	25,414
2027	21,181	2,382	1,143	596	25,301
2028	21,102	2,361	1,161	589	25,213
2029	21,052	2,338	1,180	584	25,153
2030	21,034	2,308	1,186	581	25,109
2031	21,045	2,273	1,193	579	25,090
2032	21,083	2,232	1,200	580	25,094
2033	21,146	2,190	1,206	582	25,124
2034	21,238	2,143	1,212	585	25,178
2035	21,362	2,096	1,219	590	25,267
2036	21,521	2,050	1,225	595	25,391
2037	21,707	2,004	1,231	600	25,541
2038	21,919	1,958	1,237	604	25,718
2039	22,160	1,912	1,243	609	25,925
2040	22,432	1,866	1,248	614	26,160

Table 0-67 Baseline (50-State) NO_x Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	779,842	86,861	37,690	38,466	942,858
2007	770,409	87,803	38,293	36,409	932,914
2008	761,768	87,623	38,906	34,361	922,658
2009	755,490	88,573	39,528	32,338	915,929
2010	745,431	88,625	40,161	30,370	904,587
2011	735,641	89,586	40,803	28,459	894,490
2012	730,031	88,909	41,456	27,212	887,608
2013	726,116	89,872	42,119	26,017	884,125
2014	722,365	89,090	42,793	24,872	879,121
2015	718,800	90,055	43,168	24,382	876,405
2016	714,893	89,682	43,544	23,325	871,445
2017	711,364	90,653	43,921	22,922	868,860
2018	708,525	90,875	44,299	22,559	866,258
2019	706,475	91,859	44,609	22,197	865,139
2020	704,353	89,367	44,917	21,836	860,474
2021	702,449	90,332	45,224	21,477	859,481
2022	700,505	89,231	45,529	21,119	856,383
2023	698,881	89,395	45,832	20,797	854,905
2024	697,737	87,896	46,134	20,510	852,277
2025	696,922	85,521	46,433	20,256	849,133
2026	696,845	85,305	46,730	20,066	848,946
2027	697,488	84,961	46,863	19,935	849,248
2028	698,814	84,538	46,989	19,860	850,202
2029	700,893	84,058	47,107	19,836	851,894
2030	703,847	83,458	47,062	19,859	854,226
2031	707,554	82,732	47,002	19,926	857,214
2032	711,989	81,917	46,929	20,033	860,868
2033	717,100	81,067	46,842	20,160	865,168
2034	722,959	80,141	46,739	20,305	870,144
2035	729,705	79,228	46,622	20,468	876,023
2036	737,374	78,332	46,488	20,631	882,826
2037	745,744	77,455	46,339	20,797	890,334
2038	754,836	76,596	46,172	20,963	898,567
2039	764,711	75,766	45,989	21,131	907,596
2040	775,388	74,931	45,788	21,300	917,407

Table 0-68 Baseline (50-State) VOC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	43,874	5,501	2,891	1,609	53,874
2007	43,762	5,566	2,937	1,589	53,853
2008	43,636	5,630	2,984	1,568	53,818
2009	43,486	5,696	3,032	1,546	53,759
2010	43,301	5,763	3,080	1,523	53,667
2011	43,100	5,830	3,129	1,500	53,559
2012	42,891	5,898	3,179	1,476	53,445
2013	42,700	5,967	3,230	1,453	53,349
2014	42,518	6,037	3,282	1,429	53,265
2015	42,323	6,108	3,335	1,404	53,169
2016	42,107	6,179	3,388	1,380	53,054
2017	41,892	6,252	3,442	1,356	52,941
2018	41,684	6,325	3,497	1,332	52,838
2019	41,478	6,399	3,553	1,307	52,738
2020	41,265	6,475	3,610	1,283	52,633
2021	41,044	6,551	3,668	1,259	52,522
2022	40,820	6,628	3,726	1,235	52,410
2023	40,596	6,664	3,786	1,212	52,259
2024	40,391	6,686	3,847	1,188	52,112
2025	40,185	6,696	3,908	1,165	51,954
2026	40,027	6,697	3,971	1,146	51,841
2027	39,916	6,685	4,034	1,132	51,768
2028	39,850	6,665	4,099	1,121	51,735
2029	39,833	6,639	4,164	1,114	51,750
2030	39,873	6,600	4,231	1,110	51,813
2031	39,961	6,547	4,299	1,109	51,917
2032	40,098	6,485	4,367	1,111	52,062
2033	40,278	6,419	4,437	1,116	52,250
2034	40,507	6,345	4,508	1,123	52,483
2035	40,793	6,271	4,580	1,132	52,776
2036	41,139	6,197	4,654	1,141	53,131
2037	41,531	6,125	4,728	1,150	53,534
2038	41,969	6,053	4,804	1,159	53,986
2039	42,459	5,983	4,881	1,169	54,491
2040	43,000	5,912	4,959	1,178	55,049

Table 0-69 Baseline (50-State) HC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/Commuter	Total
2006	41,665	5,225	2,745	1,528	51,163
2007	41,559	5,285	2,789	1,509	51,143
2008	41,439	5,347	2,834	1,489	51,109
2009	41,297	5,409	2,879	1,468	51,053
2010	41,122	5,473	2,925	1,446	50,965
2011	40,930	5,537	2,972	1,424	50,863
2012	40,733	5,601	3,019	1,402	50,755
2013	40,550	5,667	3,068	1,379	50,664
2014	40,378	5,733	3,117	1,357	50,584
2015	40,192	5,800	3,167	1,334	50,493
2016	39,988	5,868	3,217	1,311	50,384
2017	39,783	5,937	3,269	1,288	50,277
2018	39,586	6,007	3,321	1,265	50,179
2019	39,391	6,077	3,374	1,242	50,084
2020	39,188	6,149	3,428	1,219	49,984
2021	38,978	6,221	3,483	1,196	49,879
2022	38,766	6,294	3,539	1,173	49,772
2023	38,553	6,329	3,595	1,151	49,628
2024	38,358	6,350	3,653	1,129	49,489
2025	38,162	6,359	3,711	1,107	49,339
2026	38,013	6,360	3,771	1,089	49,232
2027	37,907	6,349	3,831	1,075	49,162
2028	37,844	6,330	3,892	1,064	49,131
2029	37,828	6,305	3,955	1,058	49,145
2030	37,866	6,268	4,018	1,054	49,205
2031	37,950	6,218	4,082	1,053	49,304
2032	38,079	6,159	4,148	1,055	49,441
2033	38,250	6,096	4,214	1,060	49,621
2034	38,468	6,025	4,281	1,067	49,841
2035	38,740	5,955	4,350	1,075	50,120
2036	39,068	5,885	4,419	1,084	50,457
2037	39,440	5,817	4,490	1,092	50,839
2038	39,857	5,748	4,562	1,101	51,269
2039	40,322	5,682	4,635	1,110	51,749
2040	40,836	5,614	4,709	1,119	52,278

Table 0-70 Baseline (50-State) CO Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	116,584	9,620	5,805	4,201	136,211
2007	118,450	9,774	5,898	4,234	138,356
2008	120,345	9,930	5,993	4,268	140,536
2009	122,271	10,089	6,089	4,302	142,751
2010	124,227	10,251	6,186	4,337	145,000
2011	126,215	10,415	6,285	4,371	147,286
2012	128,234	10,581	6,386	4,406	149,607
2013	130,286	10,751	6,488	4,442	151,966
2014	132,370	10,923	6,592	4,477	154,362
2015	134,488	11,097	6,697	4,513	156,796
2016	136,640	11,275	6,804	4,549	159,268
2017	138,826	11,455	6,913	4,585	161,780
2018	141,047	11,639	7,024	4,622	164,332
2019	143,304	11,825	7,136	4,659	166,924
2020	145,597	12,014	7,250	4,696	169,558
2021	147,927	12,206	7,366	4,734	172,233
2022	150,293	12,402	7,484	4,772	174,951
2023	152,698	12,600	7,604	4,810	177,712
2024	155,141	12,802	7,725	4,849	180,517
2025	157,624	13,006	7,849	4,887	183,366
2026	160,146	13,215	7,975	4,926	186,261
2027	162,708	13,426	8,102	4,966	189,202
2028	165,311	13,641	8,232	5,006	192,189
2029	167,956	13,859	8,364	5,046	195,224
2030	170,643	14,081	8,497	5,086	198,308
2031	173,374	14,306	8,633	5,127	201,440
2032	176,148	14,535	8,771	5,168	204,622
2033	178,966	14,768	8,912	5,209	207,855
2034	181,830	15,004	9,054	5,251	211,139
2035	184,739	15,244	9,199	5,293	214,475
2036	187,695	15,488	9,346	5,335	217,864
2037	190,698	15,736	9,496	5,378	221,307
2038	193,749	15,987	9,648	5,421	224,805
2039	196,849	16,243	9,802	5,464	228,359
2040	199,999	16,503	9,959	5,508	231,969

Table 0-71 Baseline (50-State) SO_2 Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	83,769	6,637	3,085	3,018	96,510
2007	85,110	6,743	3,134	3,042	98,030
2008	10,088	799	372	358	11,617
2009	10,250	812	377	361	11,800
2010	10,414	825	384	364	11,986
2011	10,580	838	390	366	12,175
2012	10,750	852	396	369	12,367
2013	312	25	11	11	359
2014	317	25	12	11	365
2015	322	26	12	11	370
2016	327	26	12	11	376
2017	333	26	12	11	382
2018	338	27	12	11	388
2019	343	27	13	11	394
2020	349	28	13	11	400
2021	354	28	13	11	407
2022	360	29	13	11	413
2023	366	29	13	12	420
2024	372	29	14	12	426
2025	378	30	14	12	433
2026	384	30	14	12	440
2027	390	31	14	12	447
2028	396	31	15	12	454
2029	402	32	15	12	461
2030	409	32	15	12	468
2031	415	33	15	12	476
2032	422	33	16	12	483
2033	429	34	16	12	491
2034	435	35	16	13	499
2035	442	35	16	13	506
2036	450	36	17	13	515
2037	457	36	17	13	523
2038	464	37	17	13	531
2039	471	37	17	13	539
2040	479	38	18	13	548

Table 0-72 Baseline (50-State) Air Toxics Emissions for Locomotives (short tons)

HAP	1999	2010	2015	2020	2030
BENZENE	92	84	82	80	76
FORMALDEHYDE	1,467	1,339	1,318	1,280	1,214
ACETALDEHYDE	640	584	575	558	530
1,3-BUTADIENE	107	98	96	93	88
ACROLEIN	104	94	93	90	86
NAPHTHALENE	58	42	40	38	34
POM	35	25	24	23	20

3.3.3 Control Inventory Development

Control inventories were developed in the same manner as the baseline inventories. The only change was in the emission factors.

3.3.3.1 Control Scenario Modeled

The proposed regulations would apply in largely the same manner as the existing program. Thus, the control scenario can be defined simply by the proposed standards and the model years for which they would become effective. Two new sets of emission standards are being proposed: line-haul locomotive standards and switch locomotive standards. The line-haul standards would apply for freight and passenger line-haul locomotives, while the switch standards would apply for freight and passenger switch locomotives. Note; we are not changing the emission standards for CO.

As in the baseline analysis, average in-use emission factors for the analysis of the proposed standards were generally assumed to be 10 percent below the applicable standards, to account for deterioration of emissions throughout the useful life, production variations, and the compliance margins that manufacturers incorporate into their designs. The exceptions to this general rule are the HC emissions for all locomotives and the NO_x emissions for Tier 4 locomotives. While we are not proposing changes to the Tier 3 or earlier HC standards, we expect the emission controls for PM_{10} will generally achieve proportional reductions in HC. For Tier 4 NO_x standards, we expect that manufacturers will need to have lower zero-hour emission rates to account for potential deterioration and include larger compliance margins (expressed as a percentage of the standards).

The emission factors used to generate the control case inventories are given in Table 0-73 and Table 0-74.

Table 0-73 Projected Line-Haul Emission Factors with Proposed Standards

Tier	Initial Model Year	NO_x (g/bhp-hr)	PM_{10} (g/bhp-hr)	HC (g/bhp-hr)
TIER 0	2008/2010[A]	8.60	0.20	0.30
TIER 1	2008/2010	6.70	0.20	0.29
TIER 2	2013	4.95	0.09	0.13
TIER 3	2012	4.95	0.09	0.13
TIER 4	2015/2017[B]	1.00	0.027	0.04

[A] The new Tier 0 standard would apply in 2008 where kits are available, and for all locomotives in 2010. This is modeled as a 40/80/100 phase-in.

[B] The Tier 4 NOx standard would not apply until 2017, while the other standards would apply starting in 2015. The Tier 4 NOx standard would apply, however, at remanufacture for model year 2015 and 2016 locomotives.

Table 0-74 Projected Switch Emission Factors with Proposed Standards

Tier	Initial Model Year	NO_x (g/bhp-hr)	PM_{10} (g/bhp-hr)	HC (g/bhp-hr)
TIER 0	2008	12.60	0.25	0.57
TIER 1	2008	9.90	0.25	0.57
TIER2	2013	7.30	0.09	0.26
TIER3	2012	5.40	0.09	0.26
TIER4	2015	1.00	0.02	0.08

3.3.3.2 Locomotive Control Inventory Summary

The control locomotive inventory is shown separately for PM_{10}, $PM_{2.5}$, NO_x, VOC, and HC in Table 0-75 through Table 0-79. See section 3.3.2.5 for CO and SO_2 inventories which are not projected to change as a result of the proposed standards.

The control air toxic inventories for locomotives are provided in Table 0-80. The gas phase air toxics are assumed to be controlled proportionately to VOC, while POM is controlled proportionately to PM.

Table 0-75 Control Case PM_{10} Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	27,919	2,270	935	1,023	32,147
2007	27,873	2,295	950	1,011	32,129
2008	24,919	2,111	883	901	28,814
2009	24,393	2,134	897	888	28,311
2010	23,777	2,109	911	848	27,645
2011	22,544	2,128	926	809	26,407
2012	21,311	2,068	940	761	25,081
2013	20,030	2,069	944	707	23,750
2014	19,279	2,015	959	663	22,916
2015	18,377	2,029	974	623	22,003
2016	17,108	1,968	990	574	20,639
2017	15,849	1,981	1,006	527	19,363
2018	14,965	1,954	1,022	480	18,422
2019	14,113	1,968	1,038	435	17,554
2020	13,567	1,851	1,055	402	16,874
2021	13,014	1,862	1,071	379	16,326
2022	12,427	1,793	1,088	355	15,664
2023	11,831	1,774	1,106	332	15,043
2024	11,246	1,687	1,124	309	14,366
2025	10,656	1,557	1,141	286	13,641
2026	10,098	1,518	1,160	265	13,041
2027	9,561	1,473	1,178	247	12,459
2028	9,045	1,425	1,197	230	11,896
2029	8,553	1,374	1,216	215	11,358
2030	8,092	1,321	1,223	201	10,837
2031	7,656	1,263	1,230	189	10,337
2032	7,243	1,200	1,237	178	9,858
2033	6,851	1,136	1,243	168	9,398
2034	6,501	1,069	1,250	158	8,978
2035	6,181	1,001	1,256	150	8,589
2036	5,905	934	1,263	143	8,244
2037	5,661	866	1,269	136	7,933
2038	5,451	799	1,275	131	7,656
2039	5,277	733	1,281	127	7,417
2040	5,140	665	1,287	124	7,216

Table 0-76 Control Case $PM_{2.5}$ Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	27,082	2,202	907	992	31,183
2007	27,037	2,226	922	981	31,166
2008	24,171	2,048	856	874	27,950
2009	23,661	2,070	870	861	27,462
2010	23,063	2,046	884	823	26,816
2011	21,868	2,064	898	785	25,614
2012	20,672	2,006	912	738	24,329
2013	19,429	2,007	916	686	23,037
2014	18,701	1,954	930	643	22,228
2015	17,826	1,968	945	604	21,343
2016	16,594	1,909	960	557	20,020
2017	15,373	1,922	975	511	18,782
2018	14,516	1,896	991	466	17,869
2019	13,690	1,909	1,007	422	17,027
2020	13,160	1,795	1,023	390	16,368
2021	12,623	1,806	1,039	367	15,836
2022	12,054	1,740	1,056	345	15,194
2023	11,476	1,721	1,073	322	14,592
2024	10,909	1,637	1,090	300	13,935
2025	10,336	1,511	1,107	277	13,232
2026	9,795	1,473	1,125	257	12,650
2027	9,274	1,429	1,143	239	12,085
2028	8,773	1,382	1,161	223	11,539
2029	8,297	1,332	1,180	208	11,017
2030	7,849	1,281	1,186	195	10,512
2031	7,426	1,225	1,193	183	10,027
2032	7,026	1,164	1,200	172	9,562
2033	6,645	1,102	1,206	163	9,116
2034	6,306	1,037	1,212	154	8,709
2035	5,996	971	1,219	145	8,331
2036	5,728	906	1,225	138	7,997
2037	5,491	840	1,231	132	7,695
2038	5,287	775	1,237	127	7,426
2039	5,118	711	1,243	123	7,195
2040	4,985	645	1,248	120	6,999

Table 0-77 Control Case NO_x Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	779,842	86,861	37,690	38,466	942,858
2007	770,409	87,803	38,293	36,409	932,914
2008	757,789	87,056	38,906	34,361	918,111
2009	751,364	87,999	39,528	32,338	911,229
2010	731,807	87,513	40,161	29,845	889,326
2011	705,203	88,324	40,803	27,408	861,738
2012	692,606	86,614	41,456	25,933	846,609
2013	679,298	87,409	42,119	24,545	833,372
2014	673,879	85,623	42,793	23,239	825,533
2015	670,297	86,221	43,168	22,879	822,565
2016	658,944	84,610	43,544	21,717	808,815
2017	628,992	85,186	43,921	20,575	778,674
2018	608,010	84,612	44,299	19,496	756,417
2019	588,239	85,177	44,609	18,438	736,463
2020	569,144	80,769	44,917	17,662	712,492
2021	549,859	81,278	45,224	16,903	693,264
2022	529,725	78,845	45,529	16,144	670,243
2023	490,882	78,025	45,832	14,732	629,471
2024	451,535	74,751	46,134	13,316	585,735
2025	431,091	70,098	46,433	12,558	560,179
2026	411,268	68,538	46,730	11,833	538,369
2027	391,811	66,724	46,863	11,182	516,581
2028	372,842	64,743	46,989	10,555	495,130
2029	354,485	62,635	47,107	9,948	474,175
2030	336,949	60,285	47,062	9,355	453,651
2031	320,021	57,681	47,002	8,775	433,480
2032	303,667	54,892	46,929	8,204	413,692
2033	287,812	52,013	46,842	7,641	394,307
2034	272,853	48,969	46,739	7,082	375,643
2035	258,735	45,924	46,622	6,527	357,807
2036	246,204	42,882	46,488	6,048	341,622
2037	234,905	39,846	46,339	5,623	326,713
2038	224,870	36,814	46,172	5,270	313,127
2039	216,190	33,806	45,989	4,986	300,970
2040	208,892	30,761	45,788	4,765	290,205

Table 0-78 Control Case VOC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	43,874	5,501	2,891	1,609	53,874
2007	43,762	5,566	2,937	1,589	53,853
2008	42,998	5,488	2,984	1,568	53,037
2009	42,008	5,552	3,032	1,546	52,137
2010	40,825	5,483	3,080	1,470	50,858
2011	38,373	5,534	3,129	1,395	48,431
2012	35,890	5,364	3,179	1,301	45,734
2013	33,597	5,413	3,230	1,210	43,451
2014	31,991	5,253	3,282	1,122	41,648
2015	30,268	5,291	3,335	1,045	39,939
2016	27,758	5,112	3,388	952	37,210
2017	25,275	5,147	3,442	861	34,725
2018	23,607	5,066	3,497	771	32,941
2019	22,010	5,100	3,553	683	31,346
2020	21,142	4,760	3,610	623	30,135
2021	20,266	4,790	3,668	586	29,310
2022	19,340	4,588	3,726	549	28,204
2023	18,402	4,538	3,786	512	27,238
2024	17,483	4,291	3,847	476	26,096
2025	16,556	3,916	3,908	439	24,819
2026	15,681	3,810	3,971	406	23,869
2027	14,839	3,692	4,034	377	22,943
2028	14,031	3,565	4,099	351	22,047
2029	13,263	3,432	4,164	328	21,187
2030	12,543	3,302	4,231	307	20,383
2031	11,863	3,160	4,299	288	19,609
2032	11,220	3,009	4,367	270	18,866
2033	10,611	2,853	4,437	255	18,156
2034	10,068	2,689	4,508	241	17,506
2035	9,573	2,525	4,580	228	16,907
2036	9,147	2,362	4,654	217	16,379
2037	8,771	2,199	4,728	207	15,906
2038	8,448	2,037	4,804	199	15,488
2039	8,182	1,876	4,881	193	15,132
2040	7,974	1,714	4,959	188	14,835

Table 0-79 Control Case HC Emissions for Locomotives (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2006	41,665	5,225	2,745	1,528	51,163
2007	41,559	5,285	2,789	1,509	51,143
2008	40,834	5,211	2,834	1,489	50,368
2009	39,894	5,272	2,879	1,468	49,513
2010	38,770	5,207	2,925	1,396	48,298
2011	36,441	5,255	2,972	1,325	45,993
2012	34,083	5,094	3,019	1,236	43,432
2013	31,906	5,141	3,068	1,149	41,264
2014	30,381	4,989	3,117	1,065	39,552
2015	28,745	5,025	3,167	993	37,929
2016	26,361	4,854	3,217	904	35,337
2017	24,003	4,888	3,269	817	32,977
2018	22,419	4,811	3,321	732	31,283
2019	20,902	4,844	3,374	648	29,769
2020	20,078	4,521	3,428	591	28,618
2021	19,246	4,549	3,483	556	27,835
2022	18,367	4,357	3,539	521	26,784
2023	17,476	4,310	3,595	487	25,867
2024	16,603	4,075	3,653	452	24,783
2025	15,722	3,719	3,711	417	23,570
2026	14,892	3,619	3,771	386	22,667
2027	14,092	3,506	3,831	358	21,788
2028	13,325	3,386	3,892	334	20,937
2029	12,595	3,259	3,955	311	20,121
2030	11,912	3,136	4,018	291	19,357
2031	11,266	3,001	4,082	273	18,622
2032	10,655	2,857	4,148	257	17,917
2033	10,077	2,709	4,214	242	17,242
2034	9,561	2,554	4,281	229	16,625
2035	9,092	2,398	4,350	216	16,056
2036	8,687	2,243	4,419	206	15,555
2037	8,330	2,089	4,490	197	15,105
2038	8,023	1,934	4,562	189	14,709
2039	7,770	1,782	4,635	183	14,370
2040	7,573	1,627	4,709	178	14,088

Table 0-80 Control Case Air Toxic Emissions for Locomotives (short tons)

HAP	2010	2015	2020	2030
BENZENE	79	62	46	30
FORMALDEHYDE	1,269	990	733	478
ACETALDEHYDE	554	432	320	208
1,3-BUTADIENE	92	72	53	35
ACROLEIN	90	70	52	34
NAPHTHALENE	40	30	22	13
POM	24	19	14	9

3.3.4 Projected Locomotive Emission Reductions from the Proposed Rule

The projected emission reductions for PM $_{2.5}$, NO_x and VOC for each category and calendar year are given in Table 0-81, Table 0-82, and Table 0-83. Table 0-84 presents the air toxic emission reductions.

Table 0-81 Projected Locomotive $PM_{2.5}$ Emission Reductions (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2008	154	49	0	0	203
2009	555	50	0	0	604
2010	1,023	96	0	24	1,144
2011	2,078	101	0	49	2,227
2012	3,128	182	0	81	3,391
2013	3,865	183	0	107	4,155
2014	4,457	259	0	135	4,850
2015	5,186	269	0	159	5,614
2016	6,260	352	0	191	6,803
2017	7,323	363	0	222	7,908
2018	8,026	413	0	253	8,692
2019	8,699	425	0	283	9,406
2020	9,070	563	0	300	9,933
2021	9,444	577	0	308	10,329
2022	9,848	669	0	316	10,832
2023	10,258	694	0	324	11,276
2024	10,668	778	0	332	11,777
2025	11,081	898	0	339	12,318
2026	11,490	926	0	348	12,764
2027	11,907	953	0	356	13,216
2028	12,329	979	0	365	13,674
2029	12,755	1,006	0	375	14,136
2030	13,185	1,027	0	385	14,597
2031	13,619	1,048	0	396	15,063
2032	14,057	1,068	0	407	15,532
2033	14,501	1,087	0	419	16,007
2034	14,932	1,106	0	432	16,470
2035	15,366	1,125	0	445	16,936
2036	15,794	1,144	0	457	17,394
2037	16,215	1,163	0	467	17,846
2038	16,632	1,182	0	477	18,291
2039	17,042	1,201	0	486	18,730
2040	17,447	1,220	0	494	19,161

Table 0-82 Projected Locomotive NO_x Emission Reductions (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2008	3,978	568	0	0	4,546
2009	4,126	575	0	0	4,700
2010	13,624	1,111	0	526	15,261
2011	30,439	1,261	0	1,051	32,751
2012	37,425	2,295	0	1,278	40,999
2013	46,819	2,463	0	1,472	50,753
2014	48,487	3,468	0	1,634	53,588
2015	48,503	3,834	0	1,503	53,840
2016	55,949	5,072	0	1,608	62,630
2017	82,372	5,467	0	2,347	90,186
2018	100,515	6,263	0	3,063	109,841
2019	118,236	6,681	0	3,759	128,676
2020	135,209	8,598	0	4,175	147,982
2021	152,589	9,054	0	4,574	166,217
2022	170,780	10,386	0	4,975	186,141
2023	207,999	11,370	0	6,065	225,434
2024	246,202	13,144	0	7,195	266,541
2025	265,831	15,424	0	7,699	288,954
2026	285,577	16,767	0	8,233	310,577
2027	305,677	18,237	0	8,753	332,667
2028	325,972	19,795	0	9,305	355,071
2029	346,408	21,423	0	9,888	377,719
2030	366,898	23,173	0	10,504	400,575
2031	387,533	25,050	0	11,151	423,735
2032	408,322	27,025	0	11,828	447,175
2033	429,288	29,054	0	12,519	470,861
2034	450,106	31,171	0	13,223	494,501
2035	470,970	33,304	0	13,941	518,215
2036	491,170	35,451	0	14,584	541,204
2037	510,838	37,609	0	15,173	563,621
2038	529,966	39,782	0	15,693	585,440
2039	548,521	41,960	0	16,145	606,626
2040	566,497	44,171	0	16,534	627,202

Table 0-83 Projected Locomotive VOC Emission Reductions (short tons)

Calendar Year	Large Line-haul	Large Switch	Small Railroads	Passenger/ Commuter	Total
2008	638	143	0	0	780
2009	1,477	144	0	0	1,622
2010	2,476	279	0	52	2,808
2011	4,727	296	0	105	5,128
2012	7,002	534	0	175	7,711
2013	9,102	554	0	242	9,899
2014	10,527	784	0	307	11,617
2015	12,054	817	0	359	13,230
2016	14,349	1,067	0	428	15,844
2017	16,617	1,104	0	495	18,217
2018	18,078	1,259	0	561	19,897
2019	19,468	1,299	0	625	21,392
2020	20,122	1,714	0	661	22,498
2021	20,778	1,760	0	674	23,212
2022	21,480	2,040	0	687	24,206
2023	22,194	2,126	0	699	25,020
2024	22,908	2,395	0	713	26,016
2025	23,629	2,780	0	726	27,135
2026	24,346	2,887	0	740	27,973
2027	25,077	2,993	0	754	28,825
2028	25,819	3,100	0	770	29,688
2029	26,570	3,207	0	786	30,563
2030	27,329	3,297	0	803	31,430
2031	28,099	3,387	0	822	32,308
2032	28,878	3,477	0	841	33,196
2033	29,667	3,566	0	861	34,095
2034	30,439	3,656	0	882	34,977
2035	31,220	3,745	0	904	35,869
2036	31,992	3,835	0	924	36,752
2037	32,759	3,926	0	943	37,628
2038	33,521	4,016	0	960	38,497
2039	34,276	4,107	0	976	39,360
2040	35,026	4,198	0	990	40,214

Table 0-84 Projected Locomotive Air Toxic Emission Reductions (short tons)

HAP	2010	2015	2020	2030
BENZENE	4	20	34	46
FORMALDEHYDE	70	328	547	736
ACETALDEHYDE	31	143	239	321
1,3-BUTADIENE	5	24	40	54
ACROLEIN	5	23	39	52
NAPHTHALENE	2	10	16	20
POM	1	5	9	12

3.4 Projected Total Emission Reductions from the Proposed Rule

The total base and control inventories, as well as emission reductions by calendar year, for $PM_{2.5}$, NO_x, and VOC are given in Table 0-85. The totals include emissions from the three major categories affected by this proposed rule: commercial marine diesel engines, recreational marine diesel engines, and locomotives. The results for $PM_{2.5}$ and NO_x are also illustrated in Figure 1 and Figure 2. Reductions by pollutant and category are also provided in Table 0-86 thru Table 0-88.

The total air toxics reductions are provided in Table 0-89.

Calendar year 2040 was chosen as the end date for the analysis; however, additional reductions are expected to occur beyond this date.

Figure 1 Estimated PM2.5 Reductions from Locomotive and Marine Diesel Engine Standards (short tons)

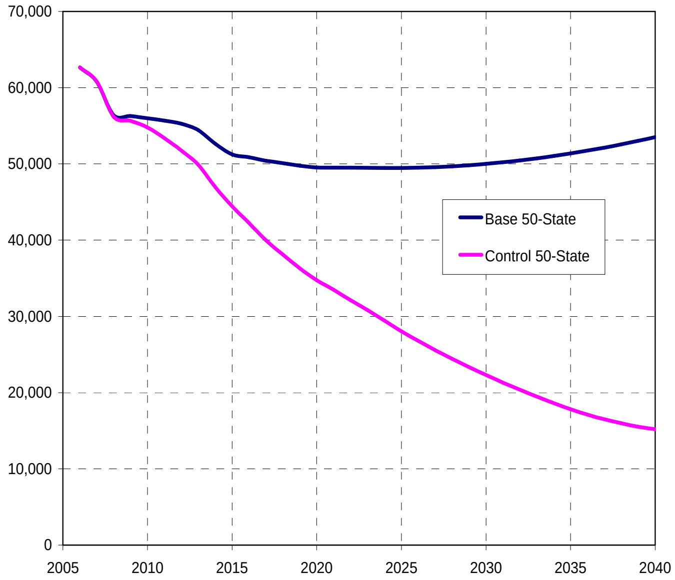

Figure 2 Estimated NOx Reductions from Locomotive and Marine Diesel Engine Standards (short tons)

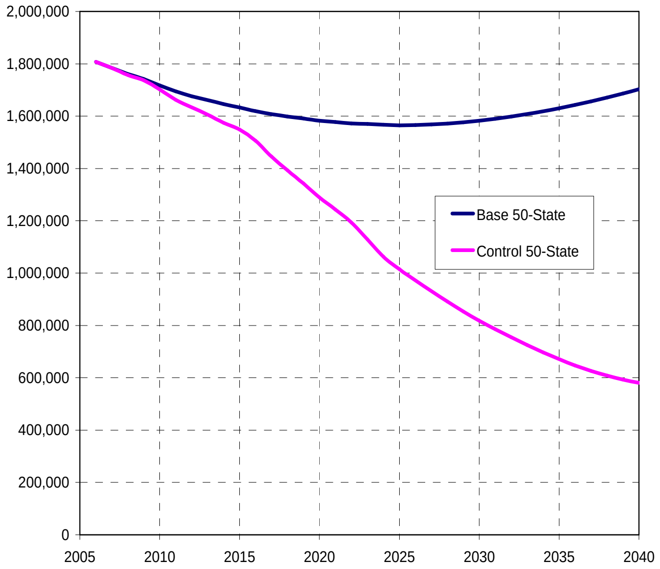

Table 0-85 Total Emissions and Projected Reductions (short tons)

Year	$PM_{2.5}$			NO_X			VOC		
	Base	Control	Reduction	Base	Control	Reduction	Base	Control	Reduction
2006	62,653	62,653	0	1,807,216	1,807,216	0	72,872	72,872	0
2007	60,785	60,785	0	1,784,284	1,784,284	0	72,776	72,776	0
2008	56,405	56,202	203	1,761,171	1,756,625	4,546	72,667	71,887	780
2009	56,302	55,694	608	1,741,683	1,736,983	4,700	72,541	70,912	1,629
2010	55,976	54,826	1,149	1,717,796	1,702,535	15,261	72,386	69,562	2,824
2011	55,667	53,431	2,236	1,695,396	1,662,645	32,751	72,219	67,068	5,151
2012	55,283	51,813	3,469	1,676,501	1,633,993	42,508	72,052	64,182	7,870
2013	54,424	49,943	4,481	1,661,733	1,605,845	55,888	71,909	61,608	10,301
2014	52,646	47,011	5,635	1,646,170	1,574,799	71,371	71,784	59,291	12,494
2015	51,240	44,466	6,775	1,633,374	1,549,093	84,281	71,657	57,077	14,580
2016	50,872	42,313	8,560	1,618,865	1,506,062	112,803	71,528	53,750	17,778
2017	50,424	40,026	10,397	1,608,049	1,445,528	162,520	71,437	50,613	20,824
2018	50,095	38,133	11,962	1,598,602	1,392,149	206,453	71,388	48,170	23,218
2019	49,764	36,308	13,455	1,591,433	1,341,927	249,506	71,359	45,937	25,421
2020	49,543	34,767	14,776	1,582,106	1,289,199	292,907	71,357	44,126	27,231
2021	49,514	33,501	16,013	1,577,901	1,242,771	335,130	71,382	42,738	28,645
2022	49,514	32,145	17,369	1,572,450	1,193,565	378,885	71,420	41,090	30,330
2023	49,496	30,821	18,675	1,569,867	1,128,045	441,821	71,431	39,604	31,827
2024	49,481	29,436	20,045	1,567,335	1,061,013	506,322	71,456	37,963	33,493
2025	49,473	28,027	21,446	1,564,909	1,013,286	551,623	71,477	36,228	35,249
2026	49,505	26,772	22,733	1,566,090	970,582	595,508	71,547	34,867	36,680
2027	49,575	25,572	24,003	1,568,322	929,227	639,095	71,659	33,581	38,077
2028	49,683	24,424	25,258	1,571,677	889,403	682,274	71,817	32,369	39,448
2029	49,831	23,330	26,501	1,576,224	851,600	724,624	72,027	31,228	40,799
2030	50,009	22,290	27,719	1,582,353	816,578	765,775	72,290	30,184	42,106
2031	50,219	21,303	28,916	1,589,972	784,030	805,941	72,597	29,208	43,389
2032	50,460	20,363	30,097	1,598,625	753,109	845,516	72,950	28,293	44,657
2033	50,733	19,462	31,271	1,608,222	723,487	884,735	73,349	27,432	45,917
2034	51,032	18,612	32,420	1,618,723	695,357	923,366	73,794	26,651	47,144
2035	51,368	17,812	33,557	1,630,331	668,881	961,451	74,302	25,939	48,364
2036	51,741	17,097	34,644	1,643,034	645,058	997,976	74,873	25,320	49,553
2037	52,142	16,482	35,660	1,656,625	624,387	1,032,239	75,493	24,787	50,705
2038	52,572	15,953	36,620	1,671,116	606,737	1,064,379	76,163	24,337	51,826
2039	53,034	15,507	37,527	1,686,564	591,798	1,094,766	76,888	23,968	52,920
2040	53,526	15,166	38,360	1,702,935	579,393	1,123,542	77,667	23,684	53,983

Table 0-86 Projected Total $PM_{2.5}$ Emission Reductions (short tons)

YEAR	COMMERCIAL MARINE	RECREATIONAL MARINE	LOCOMOTIVES	TOTAL
2008	0	0	203	203
2009	3	0	604	608
2010	6	0	1,144	1,149
2011	8	1	2,227	2,236
2012	76	3	3,391	3,469
2013	321	5	4,155	4,481
2014	776	8	4,850	5,635
2015	1,149	12	5,614	6,775
2016	1,740	16	6,803	8,560
2017	2,469	21	7,908	10,397
2018	3,245	25	8,692	11,962
2019	4,019	30	9,406	13,455
2020	4,808	35	9,933	14,776
2021	5,644	41	10,329	16,013
2022	6,491	46	10,832	17,369
2023	7,347	52	11,276	18,675
2024	8,210	58	11,777	20,045
2025	9,064	63	12,318	21,446
2026	9,899	70	12,764	22,733
2027	10,711	76	13,216	24,003
2028	11,503	82	13,674	25,258
2029	12,277	88	14,136	26,501
2030	13,027	95	14,597	27,719
2031	13,752	101	15,063	28,916
2032	14,458	107	15,532	30,097
2033	15,151	112	16,007	31,271
2034	15,834	116	16,470	32,420
2035	16,500	120	16,936	33,557
2036	17,126	124	17,394	34,644
2037	17,686	127	17,846	35,660
2038	18,198	130	18,291	36,620
2039	18,664	133	18,730	37,527
2040	19,063	136	19,161	38,360

Table 0-87 Projected Total NO_x Emission Reductions (short tons)

YEAR	COMMERCIAL MARINE	RECREATIONAL MARINE	LOCOMOTIVES	TOTAL
2008	0	0	4,546	4,546
2009	0	0	4,700	4,700
2010	0	0	15,261	15,261
2011	0	0	32,751	32,751
2012	1,463	47	40,999	42,508
2013	4,935	200	50,753	55,888
2014	17,326	458	53,588	71,371
2015	29,723	718	53,840	84,281
2016	49,151	1,022	62,630	112,803
2017	71,006	1,328	90,186	162,520
2018	94,975	1,637	109,841	206,453
2019	118,882	1,947	128,676	249,506
2020	142,666	2,260	147,982	292,907
2021	166,339	2,574	166,217	335,130
2022	189,855	2,889	186,141	378,885
2023	213,181	3,206	225,434	441,821
2024	236,257	3,524	266,541	506,322
2025	258,828	3,842	288,954	551,623
2026	280,771	4,160	310,577	595,508
2027	301,951	4,477	332,667	639,095
2028	322,410	4,793	355,071	682,274
2029	341,797	5,108	377,719	724,624
2030	359,780	5,419	400,575	765,775
2031	376,481	5,725	423,735	805,941
2032	392,324	6,016	447,175	845,516
2033	407,598	6,277	470,861	884,735
2034	422,367	6,498	494,501	923,366
2035	436,542	6,693	518,215	961,451
2036	449,899	6,873	541,204	997,976
2037	461,578	7,039	563,621	1,032,239
2038	471,739	7,199	585,440	1,064,379
2039	480,787	7,353	606,626	1,094,766
2040	488,838	7,502	627,202	1,123,542

Table 0-88 Projected Total VOC Emission Reductions (short tons)

YEAR	COMMERCIAL MARINE	RECREATIONAL MARINE	LOCOMOTIVES	TOTAL
2008	0	0	780	780
2009	7	1	1,622	1,629
2010	14	1	2,808	2,824
2011	22	2	5,128	5,151
2012	152	8	7,711	7,870
2013	383	20	9,899	10,301
2014	837	40	11,617	12,494
2015	1,290	61	13,230	14,580
2016	1,848	86	15,844	17,778
2017	2,497	111	18,217	20,824
2018	3,183	137	19,897	23,218
2019	3,867	163	21,392	25,421
2020	4,545	188	22,498	27,231
2021	5,218	215	23,212	28,645
2022	5,883	241	24,206	30,330
2023	6,539	267	25,020	31,827
2024	7,183	294	26,016	33,493
2025	7,794	320	27,135	35,249
2026	8,360	347	27,973	36,680
2027	8,880	373	28,825	38,077
2028	9,360	400	29,688	39,448
2029	9,811	426	30,563	40,799
2030	10,225	452	31,430	42,106
2031	10,605	477	32,308	43,389
2032	10,960	501	33,196	44,657
2033	11,300	523	34,095	45,917
2034	11,625	541	34,977	47,144
2035	11,936	558	35,869	48,364
2036	12,228	573	36,752	49,553
2037	12,490	587	37,628	50,705
2038	12,728	600	38,497	51,826
2039	12,947	613	39,360	52,920
2040	13,143	626	40,214	53,983

Table 0-89 Projected Total Air Toxic Emission Reductions (short tons)

HAP	2010	2015	2020	2030
BENZENE	5	66	198	422
FORMALDEHYDE	74	661	1,751	3,494
ACETALDEHYDE	32	308	836	1,691
1,3-BUTADIENE	5	24	42	58
ACROLEIN	5	30	62	105
NAPHTHALENE	2	13	27	44
POM	1	6	11	17

3.5 Contribution of Marine Diesel Engines and Locomotives to Baseline National Emission Inventories

This section provides the contribution of marine diesel engines and locomotives to baseline nationwide emission inventories in 2001, 2020, and 2030. The baseline represents current and future emissions with the existing standards. The calendar years correspond to those chosen for the air quality modeling.

The pollutants included in this section are directly emitted $PM_{2.5}$, NO_x, VOC, CO, and SO_2. While we do not provide estimates for other pollutants here, it should be noted that the affected engines also contribute to national ammonia (NH_3) and air toxics inventories.

3.5.1 Categories and Sources of Data

As described more fully earlier in this chapter, our current inventories for marine diesel engines and locomotives were developed using multiple methodologies, but they all are based on combining engine populations, hours of use, average engine loads, and in-use emissions factors. Locomotive emissions were calculated based on estimated current and projected fuel consumption rates. Emissions were calculated separately for the following locomotive categories: Large Railroad Line-Haul Locomotives, Large Railroad Switching (including Class II/III Switch railroads owned by Class I railroads), Other Line-Haul Locomotives (i.e., Class II/III local and regional railroads), Other Switcher/Terminal Locomotives and Passenger Locomotives. The inventories for marine diesel engines were created separately for Category 1 and 2 propulsion and auxiliary engines, including those less than or equal to 37 kW, and diesel fueled recreational marine propulsion engines.

The locomotive, commercial marine (C1 & C2), and diesel recreational marine values given for 2001 are actually 2002 estimates, since that is the base year that was used for air quality modeling. The stationary, aircraft, onroad diesel, and C3 commercial marine values are from the PM NAAQS 2001 air quality modeling platform, which is more recent than, but essentially the same as CAIR (2001 platform) for these sources. The 2030 stationary source values are set equal to 2020, since no specific estimates for 2030 stationary source emissions are available. All the stationary source values exclude "non-manmade" sources, such as fires and fugitive dust. Onroad gasoline vehicle values are from the National Mobile Inventory Model (NMIM) outputs for the final Mobile Source Air Toxics rulemaking, which includes the assumed implementation of Renewable Fuels Standards (RFS) and corrections for cold-start HC effects. Nonroad land-based diesel values are from the latest publicly released version of EPA's nonroad model (NONROAD2005a). Nonroad spark-ignition (SI) values in these tables (small SI, SI recreational marine, large SI, and SI recreational vehicles) are also from NONROAD2005a. The NONROAD2005 model runs were all run at the nationwide/annual level using single default nationwide temperature & RVP, using the full 50-state equipment population including all California equipment.

3.5.2 $PM_{2.5}$ Contributions to Baseline

Table 0-90 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source diesel and to total man-made $PM_{2.5}$ emissions. $PM_{2.5}$ emissions from these sources are 18 percent of the mobile source diesel $PM_{2.5}$ emissions in 2001, and this percentage increases to about 65 percent by 2030. $PM_{2.5}$ emissions from the affected sources decreases from 59,000 tons in 2002 to 50,000 tons in 2020 due to the existing emission standards. From 2020 to 2025 emissions remain relatively constant as growth offsets the effect of continued turnover of older engines to engines meeting the existing emission standards. These emissions begin to increase again around 2025 and exceed 2015 levels by 2035.

3.5.3 NO_x Contributions to Baseline

Table 0-91 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source NO_x and to total man-made NO_x emissions. NO_x emissions from these sources are 16 percent of the mobile source NO_x emissions in 2001, and this percentage increases to 35 percent by 2030. NO_x emissions from affected sources decrease from 1,993,000 tons in 2002 to 1,582,000 tons in 2020 due to the existing emission standards. From 2020 to 2025 emissions remain relatively constant as growth offsets the effect of continued turnover of older engines to engines meeting the existing emission standards. These emissions begin to increase again in 2025 and by 2035 exceed 2015 emission levels.

3.5.4 VOC Contributions to Baseline

Table 0-92 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source VOC and to total man-made VOC emissions. Due to the efficient combustion in diesel engines, mobile source VOC emissions are dominated by spark-ignition engines, and the VOC emissions from the affected sources are only 0.8 percent of the mobile source VOC in 2001, increasing to 1.3 percent by 2030. VOC emissions from affected sources increase from 67,000 tons in 2002 to 71,000 tons in 2020 and 72,000 tons in 2030, since the existing emission standards are not aimed at controlling VOC.

3.5.5 CO Contributions to Baseline

Table 0-93 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source carbon monoxide (CO) and to total man-made CO emissions. As with VOC, mobile source CO emissions are dominated by spark-ignition engines, so the CO emissions from the affected sources are only 0.3 percent of the mobile source CO in 2001, increasing to 0.5 percent by 2030. CO emissions from affected sources increase from 281,000 tons in 2002 to 319,000 tons in 2020 and 353,000 tons in 2030, since the existing emission standards are not aimed at controlling CO.

3.5.6 SO_2 Contributions to Baseline

Table 0-94 provides the contribution of locomotives and diesel-fueled recreational and commercial marine engines to mobile source SO_2 and to total man-made SO_2 emissions. SO_2 emissions from these sources are 21 percent of the mobile source SO_2 emissions in 2001, and this percentage decreases significantly to about one percent in 2020 and 2030 due to existing diesel fuel sulfur standards. SO_2 emissions from affected sources decrease from 162,000 tons in 2002 to 3,700 tons in 2020. From 2020 to 2030 emissions increase to 4,200 tons due to continued projected growth in these sectors.

Table 0-90 50-State Annual PM $_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

Category	**2001***			**2020**			**2030**		
	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total	short tons	% of diesel mobile	% of total
Locomotive	29,660	8.9%	1.2%	26,301	23.6%	1.3%	25,109	32.2%	1.2%
Recreational Marine Diesel	1,096	0.3%	0.0%	1,006	0.9%	0.0%	1,140	1.5%	0.1%
Commercial Marine (C1 & C2)	28,730	8.6%	1.2%	22,236	20.0%	1.1%	23,760	30.5%	1.1%
Land-Based Nonroad Diesel	164,180	49.2%	6.8%	46,075	41.4%	2.2%	17,934	23.0%	0.9%
Commercial Marine (C3)**	20,023	-	0.8%	36,141	-	1.7%	52,682	-	2.5%
Small Nonroad SI	25,575		1.1%	31,083		1.5%	35,761		1.7%
Recreational Marine SI	17,101		0.7%	6,595		0.3%	6,378		0.3%
SI Recreational Vehicles	12,301		0.5%	11,773		0.6%	9,953		0.5%
Large Nonroad SI (>25hp)	1,610		0.1%	2,421		0.1%	2,844		0.1%
Aircraft	5,664		0.2%	7,044		0.3%	8,569		0.4%
Total Off Highway	305,941		12.6%	190,675		9.2%	184,130		8.9%
Highway Diesel	109,952	33.0%	4.5%	15,800	14.2%	0.8%	10,072	12.9%	0.5%
Highway non-diesel	50,277		2.1%	47,354		2.3%	56,734		2.7%
Total Highway	160,229		6.6%	63,154		3.0%	66,806		3.2%
Total Diesel (distillate) Mobile	333,619	100%	13.7%	111,418	100%	5.4%	78,015	100%	3.8%
Total Mobile Sources	466,170		19.2%	253,829		12.3%	250,936		12.1%
Stationary Point and Area Sources	1,963,264		80.8%	1,817,722		87.7%	1,817,722		87.9%
Total Man-Made Sources	2,429,434		100%	2,071,551		100%	2,068,658		100%

* The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

** This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 0-91 50-State Annual NO_x Baseline Emission Levels for Mobile and Other Source Categories

Category	2001*			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	1,118,786	9.0%	5.1%	860,474	17.2%	7.8%	854,226	19.0%	8.1%
Recreational Marine Diesel	40,437	0.3%	0.2%	45,477	0.9%	0.4%	48,102	1.1%	0.5%
Commercial Marine (C1 & C2)	834,025	6.7%	3.8%	676,154	13.6%	6.1%	680,025	15.1%	6.4%
Land-Based Nonroad Diesel	1,548,236	12.5%	7.1%	678,377	13.6%	6.1%	434,466	9.7%	4.1%
Commercial Marine (C3)**	224,100	1.8%	1.0%	369,160	7.4%	3.3%	531,641	11.8%	5.0%
Small Nonroad SI	100,319	0.8%	0.5%	98,620	2.0%	0.9%	114,287	2.5%	1.1%
Recreational Marine SI	42,252	0.3%	0.2%	83,312	1.7%	0.8%	92,188	2.1%	0.9%
SI Recreational Vehicles	5,488	0.0%	0.0%	17,496	0.4%	0.2%	20,136	0.4%	0.2%
Large Nonroad SI (>25hp)	321,098	2.6%	1.5%	46,319	0.9%	0.4%	46,253	1.0%	0.4%
Aircraft	83,764	0.7%	0.4%	105,133	2.1%	0.9%	118,740	2.6%	1.1%
Total Off Highway	4,318,505	34.8%	19.8%	2,980,523	59.7%	26.9%	2,940,064	65.5%	27.7%
Highway Diesel	3,750,886	30.2%	17.2%	646,961	13.0%	5.8%	260,915	5.8%	2.5%
Highway non-diesel	4,354,430	35.0%	20.0%	1,361,276	27.3%	12.3%	1,289,780	28.7%	12.2%
Total Highway	8,105,316	65.2%	37.2%	2,008,237	40.3%	18.1%	1,550,695	34.5%	14.6%
Total Diesel (distillate) Mobile	7,292,308	58.7%	33.5%	2,907,578	58.3%	26.2%	2,277,735	50.7%	21.5%
Total Mobile Sources	12,423,821	100%	57.0%	4,988,760	100%	44.9%	4,490,759	100%	42.4%
Stationary Point and Area Sources	9,355,659	-	43.0%	6,111,866	-	55.1%	6,111,866	-	57.6%
Total Man-Made Sources	21,779,480	-	100%	11,100,626	-	100%	10,602,625	-	100%

* The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

** This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 0-92 50-State Annual VOC Baseline Emission Levels for Mobile and Other Source Categories

Category	**2001***			**2020**			**2030**		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	50,665	0.6%	0.3%	52,633	1.0%	0.4%	51,813	0.9%	0.4%
Recreational Marine Diesel	1,540	0.0%	0.0%	2,653	0.0%	0.0%	3,299	0.1%	0.0%
Commercial Marine (C1 & C2)	17,229	0.2%	0.1%	16,071	0.3%	0.1%	17,178	0.3%	0.1%
Land-Based Nonroad Diesel	188,884	2.3%	1.1%	76,047	1.4%	0.5%	63,144	1.1%	0.4%
Commercial Marine (C3)**	9,572	0.1%	0.1%	18,458	0.3%	0.1%	27,582	0.5%	0.2%
Small Nonroad SI	1,314,015	15.9%	7.3%	999,810	18.6%	7.2%	1,156,408	19.7%	8.1%
Recreational Marine SI	1,212,446	14.7%	6.8%	688,774	12.8%	5.0%	697,712	11.9%	4.9%
SI Recreational Vehicles	512,059	6.2%	2.9%	454,979	8.5%	3.3%	391,541	6.7%	2.7%
Large Nonroad SI (>25hp)	132,888	1.6%	0.7%	12,429	0.2%	0.1%	10,276	0.2%	0.1%
Portable Fuel Containers	244,545	3.0%	1.4%	254,479	4.7%	1.8%	288,630	4.9%	2.0%
Aircraft	22,084	0.3%	0.1%	27,644	0.5%	0.2%	30,331	0.5%	0.2%
Total Off Highway	3,705,926	44.9%	20.7%	2,603,977	48.5%	18.8%	2,737,914	46.7%	19.1%
Highway Diesel	223,519	2.7%	1.2%	123,449	2.3%	0.9%	138,758	2.4%	1.0%
Highway non-diesel	4,316,615	52.3%	24.1%	2,646,363	49.2%	19.1%	2,987,562	50.9%	20.8%
Total Highway	4,540,134	55.1%	25.3%	2,769,812	51.5%	20.0%	3,126,320	53.3%	21.8%
Total Diesel (distillate) Mobile	479,285	5.8%	2.7%	270,844	5.0%	2.0%	274,189	4.7%	1.9%
Total Mobile Sources	8,246,060	100%	46.0%	5,373,789	100%	38.8%	5,864,234	100%	40.9%
Stationary Point and Area Sources	9,692,344	-	54.0%	8,475,443	-	61.2%	8,475,443	-	59.1%
Total Man-Made Sources	17,938,404	-	100%	13,849,232	-	100%	14,339,677	-	100%

* The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

** This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 0-93 50-State Annual CO Baseline Emission Levels for Mobile and Other Source Categories

Category	2001*			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	123,210	0.1%	0.1%	169,558	0.3%	0.2%	198,308	0.3%	0.2%
Recreational Marine Diesel	6,467	0.0%	0.0%	9,374	0.0%	0.0%	10,930	0.0%	0.0%
Commercial Marine (C1 & C2)	151,331	0.2%	0.2%	139,712	0.2%	0.2%	143,791	0.2%	0.2%
Land-Based Nonroad Diesel	893,320	1.0%	0.9%	310,258	0.5%	0.4%	155,625	0.2%	0.2%
Commercial Marine (C3)**	19,391	0.0%	0.0%	37,459	0.1%	0.1%	56,713	0.1%	0.1%
Small Nonroad SI	18,843,914	21.4%	19.4%	27,269,797	41.7%	36.8%	31,623,016	42.5%	38.1%
Recreational Marine SI	2,816,005	3.2%	2.9%	2,136,234	3.3%	2.9%	2,178,413	2.9%	2.6%
SI Recreational Vehicles	1,229,707	1.4%	1.3%	1,922,020	2.9%	2.6%	1,902,925	2.6%	2.3%
Large Nonroad SI (>25hp)	1,801,679	2.0%	1.9%	304,532	0.5%	0.4%	281,993	0.4%	0.3%
Aircraft	263,232	0.3%	0.3%	327,720	0.5%	0.4%	358,012	0.5%	0.4%
Total Off Highway	26,148,256	29.6%	26.9%	32,626,663	49.9%	44.1%	36,909,725	49.6%	44.4%
Highway Diesel	1,098,213	1.2%	1.1%	248,689	0.4%	0.3%	149,784	0.2%	0.2%
Highway non-diesel	60,985,008	69.1%	62.7%	32,503,404	49.7%	43.9%	37,399,211	50.2%	45.0%
Total Highway	62,083,221	70.4%	63.8%	32,752,093	50.1%	44.2%	37,548,995	50.4%	45.2%
Total Diesel (distillate) Mobile	2,272,530	2.6%	2.3%	877,583	1.3%	1.2%	658,428	0.9%	0.8%
Total Mobile Sources	88,231,477	100%	90.7%	65,378,756	100%	88.3%	74,458,720	100%	89.6%
Stationary Point and Area Sources	9,014,249	-	9.3%	8,641,678	-	11.7%	8,641,678	-	10.4%
Total Man-Made Sources	97,245,726	-	100%	74,020,434	-	100%	83,100,398	-	100%

* The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

** This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

Table 0-94 50-State Annual SO_2 Baseline Emission Levels for Mobile and Other Source Categories

Category	2001*			2020			2030		
	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total	short tons	% of mobile source	% of total
Locomotive	76,727	9.7%	0.5%	400	0.1%	0.0%	468	0.1%	0.0%
Recreational Marine Diesel	5,145	0.7%	0.0%	162	0.0%	0.0%	192	0.0%	0.0%
Commercial Marine (C1 & C2)	80,353	10.2%	0.5%	3,104	0.9%	0.0%	3,586	0.7%	0.0%
Land-Based Nonroad Diesel	167,615	21.2%	1.1%	999	0.3%	0.0%	1,078	0.2%	0.0%
Commercial Marine (C3)**	166,739	21.1%	1.1%	272,535	79.9%	3.2%	400,329	83.2%	4.6%
Small Nonroad SI	6,723	0.9%	0.0%	8,620	2.5%	0.1%	9,990	2.1%	0.1%
Recreational Marine SI	2,755	0.3%	0.0%	2,980	0.9%	0.0%	3,160	0.7%	0.0%
SI Recreational Vehicles	1,241	0.2%	0.0%	2,643	0.8%	0.0%	2,784	0.6%	0.0%
Large Nonroad SI (>25hp)	925	0.1%	0.0%	905	0.3%	0.0%	1,020	0.2%	0.0%
Aircraft	7,890	1.0%	0.0%	9,907	2.9%	0.1%	11,137	2.3%	0.1%
Total Off Highway	516,113	65.4%	3.3%	302,255	88.7%	3.5%	433,745	90.2%	5.0%
Highway Diesel	103,632	13.1%	0.7%	3,443	1.0%	0.0%	4,453	0.9%	0.1%
Highway non-diesel	169,125	21.4%	1.1%	35,195	10.3%	0.4%	42,709	8.9%	0.5%
Total Highway	272,757	34.6%	1.7%	38,638	11.3%	0.5%	47,162	9.8%	0.5%
Total Diesel (distillate) Mobile	433,465	54.9%	2.7%	8,108	2.4%	0.1%	9,777	2.0%	0.1%
Total Mobile Sources	788,870	100%	5.0%	340,893	100%	4.0%	480,907	100%	5.5%
Stationary Point and Area Sources	15,057,420	-	95.0%	8,215,016	-	96.0%	8,215,016	-	94.5%
Total Man-Made Sources	15,846,290	-	100%	8,555,909	-	100%	8,695,923	-	100%

* The locomotive, commercial marine (C1 & C2), and diesel recreational marine estimates are for calendar year 2002.

** This category includes emissions from Category 3 (C3) propulsion engines and C2/3 auxiliary engines used on ocean-going vessels.

3.6 Contribution of Marine Diesel Engines and Locomotives to Non-Attainment Area Emission Inventories

Table 0-95 and Table 0-96 show the percent contribution to mobile source diesel $PM_{2.5}$ and total mobile source NO_x for certain non-attainment areas where there are large rail yards and/or commercial marine ports. The county-level inventories were estimated by allocating the nationwide baseline inventories to the counties using the same county:national ratios as used in the 2002 National Emissions Inventory (NEI).[15] It can be seen that locomotives and diesel marine vessels make up a substantial portion of the $PM_{2.5}$ and NO_x mobile source inventories in these areas. For instance, the combination of rail and commercial marine activity in the Huntington-Ashland WV-KY-OH area yields a contribution over 50% of mobile source diesel PM2.5 in 2002, increasing to 90% in 2030.

These percentages are the same as shown in Chapter 2 of the Preamble of this proposed rule. Additional details, including the annual tons of PM2.5 and NOx from locomotives, diesel marine engines, and all mobile sources within each of the counties of these metropolitan areas are provided in Appendix 3A of this chapter.

Table 0-95 Locomotive and Diesel Marine Engine Contributions to Non-Attainment Area Mobile Source Diesel $PM_{2.5}$ Emissions

$PM_{2.5}$ Metropolitan Area	2002	2020	2030
	LM %	LM %	LM %
Huntington-Ashland WV-KY-OH	52.9%	82.1%	90.4%
Houston, TX	41.9%	72.9%	84.6%
Los Angeles, CA	31.3%	49.3%	72.1%
Cleveland-Akron-Lorain, OH	25.1%	56.0%	72.0%
Chicago, IL	24.6%	54.9%	70.0%
Cincinnati, OH	23.2%	53.6%	69.5%
Chattanooga, TN	21.1%	56.3%	69.5%
Kansas City, MO	20.6%	51.3%	68.0%
Baltimore, MD	22.5%	52.6%	67.8%
St. Louis, MO	21.4%	51.3%	67.5%
Philadelphia, PA	19.6%	47.0%	63.9%
Seattle, WA	17.0%	43.3%	60.4%
Birmingham, AL	16.3%	46.6%	57.5%
Minneapolis-St. Paul, MN	10.7%	31.3%	47.8%
Boston, MA	7.8%	22.9%	40.5%
San Joaquin Valley, CA	8.8%	19.4%	38.2%
Atlanta, GA	5.2%	19.6%	29.9%
Indianapolis, IN	5.0%	17.5%	29.3%
Phoenix-Mesa, AZ	4.9%	17.3%	26.8%
Detroit, MI	4.1%	15.3%	26.0%
New York, NY	3.5%	11.1%	20.3%

Table 0-96 Locomotive and Diesel Marine Engine Contributions to Non-Attainment Area Total Mobile Source NO_x Emissions

NOx Metropolitan Area	2002	2020	2030
	LM %	LM %	LM %
Houston, TX	31.5%	46.3%	44.8%
Kansas City, MO	19.3%	39.3%	43.2%
Birmingham, AL	16.7%	38.3%	42.6%
Chicago, IL	19.9%	37.8%	41.1%
Cleveland-Akron-Lorain, OH	18.8%	37.2%	39.5%
Chattanooga, TN	15.6%	35.7%	39.1%
Cincinnati, OH	17.5%	35.7%	38.3%
Los Angeles, CA	18.1%	30.8%	37.2%
St. Louis, MO	15.7%	33.8%	36.9%
Huntington-Ashland WV-KY-OH	38.1%	41.9%	36.2%
Seattle, WA	13.2%	27.7%	30.3%
San Joaquin Valley, CA	8.4%	16.0%	25.7%
Minneapolis-St. Paul, MN	8.1%	17.5%	19.4%
Philadelphia, PA	13.4%	19.7%	18.8%
Phoenix-Mesa, AZ	5.1%	11.7%	14.6%
Atlanta, GA	4.2%	10.7%	12.8%
Indianapolis, IN	4.3%	10.7%	12.7%
Boston, MA	6.3%	10.6%	10.8%
Baltimore, MD	7.1%	10.4%	9.7%
Detroit, MI	2.8%	7.2%	8.2%
New York, NY	4.7%	7.4%	7.3%

3.7 Emission Inventories Used for Air Quality Modeling

3.7.1 Comparison of Air Quality and Proposed Rule Inventories

The emission inventory estimates used to demonstrate the effect of the proposed rule on air quality relied on the best estimates available at that time of the emission contributions from all sources in the base calendar year and projections into future calendar years. However, because of the long lead time necessary to prepare inputs for the air quality models and to run the models, the emission inventory estimates used in the air quality analysis are not the inventories that are now our best estimate of the impacts of the proposed rule. In all cases, the changes to the emission inventory estimates reflect improvements made to the inventories which reflect new information about the emission contributions from various sources that was not available at the time the air quality analysis inventories were prepared. This section describes the differences in the inventories used for the air quality analysis and the inventories used for the proposed rule. Chapter 2 of this document discusses the air quality analysis results and addresses the likely impact of these differences (if any) on the air quality outcomes from the proposed rule.

In addition to the diesel locomotive, commercial marine vessel, and diesel recreational marine sources, the air quality inventories include emission contributions from all sources, including sources not directly affected by the proposed rule:

- Stationary and area sources
- Aircraft
- Oceangoing commercial marine vessels (Category 3)
- Onroad (highway) mobile sources
- Nonroad mobile sources other than diesel pleasure craft

The emission inventory estimates used in the air quality analysis for aircraft, oceangoing vessels, stationary and area sources were not updated between the air quality analysis and the proposed rule. However, changes were made in the onroad and nonroad inventories and in the locomotive and commercial marine vessel inventories for both the base (uncontrolled) and proposed rule control cases.

Table 0-97, Table 0-98, and Table 0-99 summarize the differences between the air quality inventories and the more updated proposed rule inventories for baseline VOC, NO_x, and $PM_{2.5}$. Similarly, Table 0-100, Table 0-101, and Table 0-102 summarize the differences between the air quality inventories and the more updated proposed rule inventories for control case VOC, NO_x, and $PM_{2.5}$. Lastly, Table 0-103, Table 0-104, and Table 0-105 summarize the differences in ton reductions for these pollutants between the air quality inventories and the more updated proposed rule inventories. Only the years 2020 and 2030 are shown for the latter two sets of tables, since this proposal has no benefits prior to 2008. Although the actual inventories change up to 20% depending on pollutant and year between the air quality inventories and the later proposed rule inventories, the net effect of all the changes on ton reductions of these pollutants ranges only from -4 percent to +3 percent. For the final rule air quality analysis, we will be incorporating the changes described below, as well as any future updates to the baseline estimates and control programs, which we expect will have counterbalancing impacts on both baseline and control cases for the final rule.

3.7.2 Onroad Inventory Changes

The onroad (highway) emission inventory estimates used in the air quality analysis were taken directly from the estimates used for the recent Clean Air Interstate Rule (CAIR)[16] using the National Mobile Inventory Model (NMIM) tool and the March 25, 2004, version of the NMIM County database (County20040325).

The updated emission inventory estimates for onroad in the proposed rule were originally calculated for use in the proposed Mobile Source Air Toxics (MSAT) rule. The MSAT emission inventory estimates use the NMIM tool and the July 25, 2006 version of the NMIM County database (NCD20060725MSATFinal). This new database includes important corrections to the inputs for 13 states regarding the implementation of California emission standards. The error in the old database resulted in significantly over-predicted NO_x emissions for light-duty gasoline vehicles in the onroad emission inventory estimates used in the air quality analysis, especially in the projection years of 2020 (+995,000 tons, +60%) and 2030 (+995,000 tons, +60%). This resulted in an overprediction of the ozone levels in both the base and control cases, and probably also a small overprediction of the air quality benefits of this proposed rule. Using the corrected database, light-duty gasoline NOx emissions decrease by 434,000 tons (-24%) in 2020 and 464,000 tons (-26%) in 2030.

The updated emission inventory estimates in the proposed rule for onroad also made use of an in-house version of the EPA MOBILE6.2 emission factor model which has been adapted to use new temperature correction factors for hydrocarbon (HC) emissions for light duty gasoline vehicles. These new temperature correction factors were developed as part of the MSAT rule. Using the new temperature correction factors significantly increases the HC inventories for light duty gasoline vehicles, especially in the projection years of 2020 (+995,000 tons, +60%) and 2030 (+1,358,000 tons, +83%), during periods where temperatures are less than 75 degrees Fahrenheit.

These changes do not affect the estimated ton reductions from this proposed rule, but they do affect the total emission inventory in both base and control cases. This is shown in Table 0-97 through Table 0-102 in combination with the inventory changes for nonroad equipment.

3.7.3 Nonroad Inventory Changes

The air quality analysis for the nonroad emission inventory estimates for all sources other than diesel pleasure craft (which are included in this proposed rule) were taken directly from the estimates used for the recent Clean Air Interstate Rule (CAIR) and are based on the 2004 version of the EPA NONROAD model.

The updated nonroad inventory for the proposed rule is based on the recently released 2005 version of the EPA NONROAD model. This newer nonroad model includes many changes from the 2004 version, but the ones that most significantly affect the estimated inventories are as follows:

- Addition of new evaporative categories for tank permeation, hose permeation, hot soak, and running loss emissions.
- Revised methodology for calculating diurnal emissions
- Incorporated the effects of evaporative emission standards for recreational vehicles and large spark ignition engines.
- Updated allocations from the national to the state and county level.
- Updated the power range distributions and technology fractions for spark-ignition recreational marine engines.
- Updated emission factors, deterioration factors, and technology mix for phase-2 Class 1 small gasoline engines (≤ 25 hp).

The net effect of these changes is a 55% increase in VOC from these sources (increase of 793,000 tons in 2020 and 820,000 tons in 2030). The corresponding change in NOx is a small decrease of 13,000 tons (1.4%) in 2020 and 40,000 tons (5%) in 2030. These changes do not affect the estimated ton reductions from this proposed rule, but they do affect the total emission inventory in both base and control cases. This is shown in Table 0-97 through Table 0-102 in combination with the onroad inventory changes described above in section 3.7.2.

3.7.4 Locomotive Inventory Changes

The locomotive emission inventory estimates used in the air quality analysis were calculated by EPA using a new national inventory estimation spreadsheet model developed for this purpose. However, since the air quality analysis, changes have been made in the emission rate estimates used in the model and the rate of turnover for the locomotive switcher fleet. These changes affect the emission inventory estimates for all pollutants and in all calendar years.

In addition to the changes in the model, the inventory benefits of the proposed rule were affected by a change in the assumptions for the effects of the rule. The NO_x

emissions of all Tier 0 engines were originally assumed to be affected by the rule in the locomotive emission inventory estimates used in the air quality analysis. The updated inventories assume that only 1994 and later model year Tier 0 engines are affected by the rule.

The last change to note is that the air quality inventory for locomotives treated the calculated HC inventory as if it were VOC. In the updated inventory the HC value is properly treated as Total Hydrocarbons (THC), and VOC is reported as 1.053 * THC.

The net effect of these updates is a change in tons reduced from locomotives ranging from -8 percent to +5 percent, depending on pollutant and year.

3.7.5 Commercial Marine Vessel Inventory Changes

The commercial marine vessel (Category 1 and Category 2) emission inventory estimates used in the air quality analysis were calculated by EPA using new national inventory estimation spreadsheet models developed for this purpose. However, since the air quality analysis, changes have been made in some of the assumptions used in the model, including the load factors, the sulfur content of the diesel certification fuel used for pleasure craft, and the sulfur content of diesel fuel used by commercial marine vessels. These changes did not affect the projected ton reductions for marine diesel engines, since the baseline and control cases were equally affected. These reductions are 5,000 tons VOC and 139,000 tons NO_x in 2020, and 11,000 tons VOC and 346,000 tons NO_x in 2030.

Table 0-97 50-State Annual VOC Baseline Emission Levels for Mobile and Other Source Categories

CATEGORY	2001*			2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	48,115	50,665	5.3%	49,039	52,633	7.3%	47,606	51,813	8.8%
MARINE DIESEL	14,176	18,768	32.4%	13,677	18,724	36.9%	14,588	20,477	40.4%
ALL OTHER SOURCES (MOBILE & STATIONARY)	16,978,113	17,868,970	5.2%	11,736,377	13,777,876	17.4%	11,804,110	14,267,387	20.9%
TOTAL MAN-MADE SOURCES	17,040,404	17,938,403	5.3%	11,799,094	13,849,233	17.4%	11,866,304	14,339,677	20.8%
* LOCOMOTIVE AND MARINE DIESEL VALUES IN THE "2001" COLUMN ARE ACTUALLY 2002 ESTIMATES.									

Table 0-98 50-State Annual NO$_x$ Baseline Emission Levels for Mobile and Other Source Categories

CATEGORY	2001*			2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	1,118,786	1,118,786	0.0%	844,932	860,474	1.8%	835,059	854,226	2.3%
MARINE DIESEL	711,656	874,462	22.9%	606,021	721,632	19.1%	608,761	728,127	19.6%
ALL OTHER SOURCES (MOBILE & STATIONARY)	19,854,001	19,786,232	-0.3%	10,006,926	9,518,521	-4.9%	9,570,157	9,020,273	-5.7%
TOTAL MAN-MADE SOURCES	21,684,444	21,779,480	0.4%	11,457,878	11,100,627	-3.1%	11,013,977	10,602,626	-3.7%
* LOCOMOTIVE AND MARINE DIESEL VALUES IN THE "2001" COLUMN ARE ACTUALLY 2002 ESTIMATES.									

Table 0-99 50-State Annual PM$_{2.5}$ Baseline Emission Levels for Mobile and Other Source Categories

CATEGORY	2001*			2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	29,660	29,660	0.0%	25,843	26,301	1.8%	24,334	25,109	3.2%
MARINE DIESEL	23,627	29,827	26.2%	20,087	23,242	15.7%	21,852	24,900	13.9%
ALL OTHER SOURCES (MOBILE & STATIONARY)	2,393,848	2,369,947	-1.0%	2,044,184	2,022,009	-1.1%	2,041,701	2,018,649	-1.1%
TOTAL MAN-MADE SOURCES	2,447,136	2,429,434	-0.7%	2,090,114	2,071,552	-0.9%	2,087,886	2,068,658	-0.9%
* LOCOMOTIVE AND MARINE DIESEL VALUES IN THE "2001" COLUMN ARE ACTUALLY 2002 ESTIMATES.									

Table 0-100 50-State Annual VOC Control Case Emission Levels for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	26,790	30,135	12.5%	17,394	20,383	17.2%
MARINE DIESEL	8,890	13,991	57.4%	3,969	9,801	146.9%
ALL OTHER SOURCES (MOBILE & STATIONARY)	11,736,377	13,777,876	17.4%	11,804,110	14,267,387	20.9%
TOTAL MAN-MADE SOURCES	11,772,057	13,822,002	17.4%	11,825,474	14,297,571	20.9%
* AQ MODELING FOR LOCOMOTIVES USED THC AS VOC, INSTEAD OF USING ACTUAL VOC =1.053 * THC.						

Table 0-101 50-State Annual NO_x Control Case Emission Levels for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	690,885	712,492	3.1%	452,453	453,651	0.3%
MARINE DIESEL	467,327	576,706	23.4%	262,345	362,927	38.3%
ALL OTHER SOURCES (MOBILE & STATIONARY)	10,006,926	9,518,521	-4.9%	9,570,157	9,020,273	-5.7%
TOTAL MAN-MADE SOURCES	11,165,138	10,807,720	-3.2%	10,284,956	9,836,851	-4.4%

Table 0-102 50-State Annual $PM_{2.5}$ Control Case Emission Levels for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	15,318	16,368	6.9%	9,617	10,512	9.3%
MARINE DIESEL	15,367	18,399	19.7%	8,893	11,778	32.4%
ALL OTHER SOURCES (MOBILE & STATIONARY)	2,044,184	2,022,009	-1.1%	2,041,701	2,018,649	-1.1%
TOTAL MAN-MADE SOURCES	2,074,870	2,056,776	-0.9%	2,060,211	2,040,939	-0.9%

Table 0-103 50-State Annual VOC Ton Reductions for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	22,249	22,498	1.1%	30,211	31,430	4.0%
MARINE DIESEL	4,787	4,734	-1.1%	10,619	10,676	0.5%
ALL OTHER SOURCES (MOBILE & STATIONARY)	0	0	0.0%	0	0	0.0%
TOTAL MAN-MADE SOURCES	27,036	27,231	0.7%	40,830	42,106	3.1%

Table 0-104 50-State Annual NO_x Ton Reductions for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	154,047	147,982	-3.9%	382,606	400,575	4.7%
MARINE DIESEL	138,694	144,925	4.5%	346,416	365,199	5.4%
ALL OTHER SOURCES (MOBILE & STATIONARY)	0	0	0.0%	0	0	0.0%
TOTAL MAN-MADE SOURCES	292,741	292,907	0.1%	729,022	765,775	5.0%

Table 0-105 50-State Annual $PM_{2.5}$ Ton Reductions for Mobile and Other Source Categories

CATEGORY	2020			2030		
	AQ MODELING	NPRM	% DIFF	AQ MODELING	NPRM	% DIFF
LOCOMOTIVE	10,525	9,933	-5.6%	14,717	14,597	-0.8%
MARINE DIESEL	4,720	4,843	2.6%	12,959	13,122	1.3%
ALL OTHER SOURCES (MOBILE & STATIONARY)	0	0	0.0%	0	0	0.0%
TOTAL MAN-MADE SOURCES	15,245	14,776	-3.1%	27,675	27,719	0.2%

APPENDIX 3A

Locomotive and Diesel Marine Contributions to County-Specific Mobile Source Emissions in Non-attainment Areas

Table 0-106 2002 Locomotive and Diesel Marine PM2.5 Tons/Year and Percent of Total Diesel Mobile Sources

FIPS	MSA	County	ST	2002 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
13013	Atlanta	Barrow	GA	5.77	0.01	41	14.3%
13015	Atlanta	Bartow	GA	20.64	0.20	109	19.1%
13045	Atlanta	Carroll	GA	5.65	0.08	92	6.2%
13057	Atlanta	Cherokee	GA	0.00	0.19	118	0.2%
13063	Atlanta	Clayton	GA	10.87	0.03	164	6.7%
13067	Atlanta	Cobb	GA	28.66	0.08	504	5.7%
13077	Atlanta	Coweta	GA	14.35	0.06	123	11.8%
13089	Atlanta	DeKalb	GA	13.29	0.05	440	3.0%
13097	Atlanta	Douglas	GA	5.22	0.01	68	7.7%
13113	Atlanta	Fayette	GA	3.71	0.04	86	4.4%
13117	Atlanta	Forsyth	GA	0.00	0.39	114	0.3%
13121	Atlanta	Fulton	GA	39.07	0.11	857	4.6%
13135	Atlanta	Gwinnett	GA	9.95	0.07	476	2.1%
13139	Atlanta	Hall	GA	6.62	0.65	146	5.0%
13149	Atlanta	Heard	GA	0.00	0.09	11	0.8%
13151	Atlanta	Henry	GA	14.63	0.04	154	9.5%
13217	Atlanta	Newton	GA	1.65	0.05	80	2.1%
13223	Atlanta	Paulding	GA	12.13	0.03	86	14.2%
13237	Atlanta	Putnam	GA	0.35	0.30	15	4.3%
13247	Atlanta	Rockdale	GA	2.35	0.03	71	3.4%
13255	Atlanta	Spalding	GA	0.62	0.03	53	1.2%
13297	Atlanta	Walton	GA	1.99	0.01	47	4.2%
24003	Baltimore	Anne Arundel	MD	14.68	1.82	302	5.5%
24005	Baltimore	Baltimore	MD	39.65	1.22	576	7.1%
24013	Baltimore	Carroll	MD	6.14	0.04	158	3.9%
24025	Baltimore	Harford	MD	11.40	1.18	186	6.8%
24027	Baltimore	Howard	MD	17.07	0.41	203	8.6%
24510	Baltimore	Baltimore	MD	46.07	313.45	590	60.9%
1073	Birmingham	Jefferson	AL	80.24	1.08	631	12.9%
1117	Birmingham	Shelby	AL	41.96	0.29	157	26.9%
1127	Birmingham	Walker	AL	17.15	1.08	81	22.4%
9007	Boston	Middlesex	CT	0.00	1.70	114	1.5%
25001	Boston	Barnstable	MA	7.23	20.34	179	15.4%
25005	Boston	Bristol	MA	13.57	14.82	311	9.1%
25007	Boston	Dukes	MA	0.00	133.61	143	93.4%
25009	Boston	Essex	MA	17.74	4.90	424	5.3%
25019	Boston	Nantucket	MA	0.00	19.79	29	67.4%
25021	Boston	Norfolk	MA	21.42	6.80	460	6.1%
25023	Boston	Plymouth	MA	11.20	4.99	256	6.3%
25025	Boston	Suffolk	MA	11.57	57.64	2,518	2.7%
25027	Boston	Worcester	MA	43.94	1.04	556	8.1%
33011	Boston	Hillsborough	NH	1.33	0.42	266	0.7%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
33015	Boston	Rockingham	NH	1.00	36.02	263	14.1%
47065	Chattanooga	Hamilton	TN	40.53	29.56	283	24.7%
47115	Chattanooga	Marion	TN	5.67	5.70	63	18.1%
47153	Chattanooga	Sequatchie	TN	0.00	0.00	7	0.0%
13047	Chattanooga	Catoosa	GA	12.28	0.01	52	23.6%
13083	Chattanooga	Dade	GA	11.66	0.00	46	25.3%
13295	Chattanooga	Walker	GA	0.00	0.01	48	0.0%
17031	Chicago	Cook	IL	708.71	209.67	3,661	25.1%
17043	Chicago	DuPage	IL	200.17	0.14	812	24.7%
17063	Chicago	Grundy	IL	13.55	6.45	114	17.6%
17089	Chicago	Kane	IL	70.19	0.10	371	19.0%
17093	Chicago	Kendall	IL	8.97	0.01	78	11.5%
17097	Chicago	Lake	IL	37.26	22.02	406	14.6%
17111	Chicago	McHenry	IL	20.29	0.16	189	10.8%
17197	Chicago	Will	IL	186.94	4.74	498	38.5%
18089	Chicago	Lake	IN	129.22	14.34	541	26.5%
18127	Chicago	Porter	IN	45.64	12.55	216	26.9%
18029	Cincinnati	Dearborn	IN	6.21	22.72	92	31.3%
21015	Cincinnati	Boone	KY	8.45	34.08	133	31.9%
21037	Cincinnati	Campbell	KY	16.05	23.57	95	41.5%
21117	Cincinnati	Kenton	KY	30.93	11.78	147	29.1%
39017	Cincinnati	Butler	OH	45.48	0.05	279	16.3%
39025	Cincinnati	Clermont	OH	1.96	44.98	181	25.9%
39061	Cincinnati	Hamilton	OH	44.25	133.23	737	24.1%
39165	Cincinnati	Warren	OH	6.75	0.09	192	3.6%
39007	Cleveland	Ashtabula	OH	30.49	178.56	310	67.4%
39035	Cleveland	Cuyahoga	OH	83.10	122.90	1,119	18.4%
39085	Cleveland	Lake	OH	21.22	26.15	190	25.0%
39093	Cleveland	Lorain	OH	50.28	113.72	414	39.6%
39103	Cleveland	Medina	OH	15.82	0.06	166	9.6%
39133	Cleveland	Portage	OH	31.34	0.24	198	15.9%
39153	Cleveland	Summit	OH	25.49	0.17	392	6.5%
26093	Detroit	Livingston	MI	2.47	0.07	174	1.5%
26099	Detroit	Macomb	MI	3.83	5.35	437	2.1%
26115	Detroit	Monroe	MI	18.09	8.90	198	13.6%
26125	Detroit	Oakland	MI	15.09	4.59	781	2.5%
26147	Detroit	St. Clair	MI	7.39	21.37	224	12.8%
26161	Detroit	Washtenaw	MI	4.04	0.05	269	1.5%
26163	Detroit	Wayne	MI	29.94	10.03	1,140	3.5%
48039	Houston	Brazoria	TX	18.79	247.18	463	57.4%
48071	Houston	Chambers	TX	1.07	7.41	57	14.8%
48157	Houston	Fort Bend	TX	26.30	0.09	270	9.8%
48167	Houston	Galveston	TX	13.07	566.43	751	77.1%
48201	Houston	Harris	TX	68.97	1,477.09	3,940	39.2%
48291	Houston	Liberty	TX	28.79	3.02	112	28.3%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
48339	Houston	Montgomery	TX	22.38	0.27	300	7.5%
48473	Houston	Waller	TX	6.50	0.04	45	14.5%
21019	Huntington	Boyd	KY	11.13	18.28	65	45.2%
21127	Huntington	Lawrence	KY	10.86	5.94	33	51.6%
39001	Huntington	Adams	OH	0.39	52.61	88	60.0%
39053	Huntington	Gallia	OH	3.44	23.13	62	42.8%
39087	Huntington	Lawrence	OH	12.48	34.34	86	54.5%
39145	Huntington	Scioto	OH	27.95	33.28	124	49.5%
54011	Huntington	Cabell	WV	24.48	25.26	112	44.5%
54053	Huntington	Mason	WV	6.12	39.72	92	50.0%
54099	Huntington	Wayne	WV	30.53	60.21	133	68.1%
18011	Indianapolis	Boone	IN	6.78	0.06	120	5.7%
18057	Indianapolis	Hamilton	IN	0.16	0.62	224	0.3%
18059	Indianapolis	Hancock	IN	5.17	0.03	107	4.9%
18063	Indianapolis	Hendricks	IN	18.14	0.03	188	9.7%
18081	Indianapolis	Johnson	IN	0.91	0.21	115	1.0%
18095	Indianapolis	Madison	IN	16.17	0.12	156	10.5%
18097	Indianapolis	Marion	IN	31.30	1.34	662	4.9%
18109	Indianapolis	Morgan	IN	0.41	0.22	93	0.7%
18145	Indianapolis	Shelby	IN	7.35	0.02	102	7.2%
20091	Kansas City	Johnson	KS	55.73	0.04	481	11.6%
20103	Kansas City	Leavenworth	KS	14.29	0.50	84	17.6%
20121	Kansas City	Miami	KS	81.56	0.15	139	58.6%
20209	Kansas City	Wyandotte	KS	30.24	4.47	148	23.5%
29037	Kansas City	Cass	MO	16.72	0.12	110	15.3%
29047	Kansas City	Clay	MO	28.19	4.43	188	17.3%
29049	Kansas City	Clinton	MO	0.00	0.16	49	0.3%
29095	Kansas City	Jackson	MO	90.00	33.46	646	19.1%
29107	Kansas City	Lafayette	MO	23.25	4.16	124	22.1%
29165	Kansas City	Platte	MO	22.68	0.84	151	15.6%
29177	Kansas City	Ray	MO	44.83	3.97	108	45.2%
6037	Los Angeles	Los Angeles	CA	241.14	1,666.68	5,016	38.0%
6059	Los Angeles	Orange	CA	63.57	176.82	1,696	14.2%
6065	Los Angeles	Riverside	CA	109.12	1.01	872	12.6%
6071	Los Angeles	San Bernardino	CA	359.75	0.47	1,040	34.6%
6111	Los Angeles	Ventura	CA	12.49	231.21	524	46.5%
27003	Minneapolis	Anoka	MN	21.27	12.73	232	14.7%
27019	Minneapolis	Carver	MN	0.05	0.79	82	1.0%
27037	Minneapolis	Dakota	MN	12.70	11.89	278	8.9%
27053	Minneapolis	Hennepin	MN	31.68	35.83	870	7.8%
27123	Minneapolis	Ramsey	MN	12.03	11.31	349	6.7%
27139	Minneapolis	Scott	MN	2.70	1.38	94	4.3%
27163	Minneapolis	Washington	MN	23.15	50.70	237	31.1%
9001	New York	Fairfield	CT	0.00	44.84	705	6.4%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
9005	New York	Litchfield	CT	0.00	0.89	109	0.8%
34003	New York	Bergen	NJ	26.97	3.48	512	6.0%
34013	New York	Essex	NJ	6.64	0.99	416	1.8%
34017	New York	Hudson	NJ	22.70	27.96	402	12.6%
34019	New York	Hunterdon	NJ	9.60	0.33	185	5.4%
34023	New York	Middlesex	NJ	12.54	4.94	421	4.1%
34025	New York	Monmouth	NJ	10.14	29.48	418	9.5%
34027	New York	Morris	NJ	6.96	0.53	300	2.5%
34029	New York	Ocean	NJ	0.52	13.26	256	5.4%
34031	New York	Passaic	NJ	6.11	0.51	233	2.8%
34035	New York	Somerset	NJ	13.21	0.02	195	6.8%
34037	New York	Sussex	NJ	0.99	0.63	113	1.4%
34039	New York	Union	NJ	11.04	17.95	355	8.2%
36005	New York	Bronx	NY	0.13	0.75	372	0.2%
36047	New York	Kings	NY	0.00	1.30	696	0.2%
36059	New York	Nassau	NY	0.00	11.73	518	2.3%
36061	New York	New York	NY	0.00	0.54	1,296	0.0%
36071	New York	Orange	NY	9.19	2.55	288	4.1%
36081	New York	Queens	NY	0.06	2.02	982	0.2%
36085	New York	Richmond	NY	0.00	2.29	166	1.4%
36087	New York	Rockland	NY	6.91	2.69	125	7.7%
36103	New York	Suffolk	NY	0.00	39.17	690	5.7%
36119	New York	Westchester	NY	0.00	3.76	479	0.8%
10003	Philadelphia	New Castle	DE	22.95	47.44	458	15.4%
24015	Philadelphia	Cecil	MD	9.27	1.70	125	8.7%
24029	Philadelphia	Kent	MD	0.07	1.41	42	3.6%
24031	Philadelphia	Montgomery	MD	28.82	0.53	485	6.0%
34005	Philadelphia	Burlington	NJ	0.00	54.50	328	16.6%
34007	Philadelphia	Camden	NJ	4.82	21.83	273	9.8%
34011	Philadelphia	Cumberland	NJ	0.57	55.22	155	36.0%
34015	Philadelphia	Gloucester	NJ	0.80	29.18	214	14.0%
34021	Philadelphia	Mercer	NJ	5.56	6.66	277	4.4%
34033	Philadelphia	Salem	NJ	0.27	16.91	86	19.9%
42017	Philadelphia	Bucks	PA	2.29	1.20	330	1.1%
42029	Philadelphia	Chester	PA	11.62	0.16	328	3.6%
42045	Philadelphia	Delaware	PA	4.55	193.17	409	48.4%
42101	Philadelphia	Philadelphia	PA	6.45	339.10	922	37.5%
4013	Phoenix	Maricopa	AZ	98.35	0.78	2,828	3.5%
4021	Phoenix	Pinal	AZ	52.54	0.17	256	20.6%
6019	San Joaquin	Fresno	CA	17.77	0.58	647	2.8%
6029	San Joaquin	Kern	CA	92.07	0.22	635	14.5%
6031	San Joaquin	Kings	CA	2.57	0.02	155	1.7%
6039	San Joaquin	Madera	CA	18.89	0.16	145	13.2%
6047	San Joaquin	Merced	CA	17.75	0.46	218	8.4%
6077	San Joaquin	San Joaquin	CA	29.94	30.32	437	13.8%

FIPS	MSA	County	ST	2002 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
6099	San Joaquin	Stanislaus	CA	12.07	0.24	267	4.6%
6107	San Joaquin	Tulare	CA	26.68	0.16	340	7.9%
53029	Seattle	Island	WA	0.00	19.63	69	28.5%
53033	Seattle	King	WA	28.95	191.88	1,568	14.1%
53035	Seattle	Kitsap	WA	0.00	1.27	134	0.9%
53045	Seattle	Mason	WA	0.00	0.58	37	1.6%
53053	Seattle	Pierce	WA	18.18	173.52	612	31.3%
53061	Seattle	Snohomish	WA	36.65	29.32	471	14.0%
53067	Seattle	Thurston	WA	10.80	12.02	179	12.7%
17027	St. Louis	Clinton	IL	23.14	0.08	99	23.5%
17083	St. Louis	Jersey	IL	1.86	19.07	65	32.1%
17119	St. Louis	Madison	IL	7.81	10.33	247	7.4%
17133	St. Louis	Monroe	IL	37.61	16.72	104	52.1%
17163	St. Louis	St. Clair	IL	8.93	19.78	229	12.5%
29055	St. Louis	Crawford	MO	5.23	0.04	45	11.6%
29071	St. Louis	Franklin	MO	31.20	2.36	153	21.9%
29099	St. Louis	Jefferson	MO	8.38	16.93	186	13.6%
29113	St. Louis	Lincoln	MO	13.80	6.69	87	23.4%
29183	St. Louis	St. Charles	MO	16.62	15.02	244	13.0%
29189	St. Louis	St. Louis	MO	26.77	19.32	831	5.5%
29219	St. Louis	Warren	MO	2.82	2.31	47	10.9%
29510	St. Louis	St. Louis	MO	23.28	261.28	456	62.4%

Table 0-107 2020 Locomotive and Diesel Marine PM2.5 Tons/Year and Percent of Total Diesel Mobile Sources

FIPS	MSA	County	ST	2020 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
13013	Atlanta	Barrow	GA	5.45	0.01	11	49.6%
13015	Atlanta	Bartow	GA	19.49	0.17	35	56.9%
13045	Atlanta	Carroll	GA	5.28	0.07	19	27.6%
13057	Atlanta	Cherokee	GA	0.00	0.17	23	0.7%
13063	Atlanta	Clayton	GA	10.27	0.02	41	25.2%
13067	Atlanta	Cobb	GA	26.96	0.07	137	19.8%
13077	Atlanta	Coweta	GA	13.55	0.05	33	41.2%
13089	Atlanta	DeKalb	GA	12.49	0.04	103	12.1%
13097	Atlanta	Douglas	GA	4.86	0.01	16	30.0%
13113	Atlanta	Fayette	GA	3.50	0.03	20	18.0%
13117	Atlanta	Forsyth	GA	0.00	0.35	24	1.5%
13121	Atlanta	Fulton	GA	36.74	0.09	224	16.4%
13135	Atlanta	Gwinnett	GA	9.33	0.06	118	8.0%
13139	Atlanta	Hall	GA	5.67	0.57	31	19.9%
13149	Atlanta	Heard	GA	0.00	0.08	2	4.4%
13151	Atlanta	Henry	GA	13.81	0.03	41	34.2%
13217	Atlanta	Newton	GA	1.56	0.04	15	10.4%
13223	Atlanta	Paulding	GA	11.45	0.02	24	47.5%
13237	Atlanta	Putnam	GA	0.31	0.26	3	17.2%
13247	Atlanta	Rockdale	GA	2.22	0.02	16	14.2%
13255	Atlanta	Spalding	GA	0.59	0.02	10	6.4%
13297	Atlanta	Walton	GA	1.88	0.01	10	18.8%
24003	Baltimore	Anne Arundel	MD	10.36	1.57	73	16.4%
24005	Baltimore	Baltimore	MD	34.68	1.03	154	23.1%
24013	Baltimore	Carroll	MD	5.34	0.03	37	14.6%
24025	Baltimore	Harford	MD	8.84	1.00	46	21.5%
24027	Baltimore	Howard	MD	12.62	0.32	56	22.9%
24510	Baltimore	Baltimore	MD	46.50	242.61	328	88.1%
1073	Birmingham	Jefferson	AL	75.36	0.86	188	40.6%
1117	Birmingham	Shelby	AL	39.49	0.26	65	61.4%
1127	Birmingham	Walker	AL	14.91	0.86	30	52.9%
9007	Boston	Middlesex	CT	0.00	1.50	22	6.7%
25001	Boston	Barnstable	MA	6.28	16.59	55	41.7%
25005	Boston	Bristol	MA	11.82	11.64	79	29.6%
25007	Boston	Dukes	MA	0.00	103.75	106	97.6%
25009	Boston	Essex	MA	15.42	4.13	101	19.4%
25019	Boston	Nantucket	MA	0.00	15.54	18	85.4%
25021	Boston	Norfolk	MA	18.39	5.32	114	20.9%
25023	Boston	Plymouth	MA	9.78	4.30	65	21.8%
25025	Boston	Suffolk	MA	9.83	44.70	688	7.9%
25027	Boston	Worcester	MA	37.77	0.92	142	27.3%
33011	Boston	Hillsborough	NH	1.15	0.37	56	2.7%

FIPS	MSA	County	ST	2020 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
33015	Boston	Rockingham	NH	0.87	28.09	74	39.1%
47065	Chattanooga	Hamilton	TN	38.28	22.98	103	59.3%
47115	Chattanooga	Marion	TN	5.36	4.45	18	53.8%
47153	Chattanooga	Sequatchie	TN	0.00	0.00	1	0.0%
13047	Chattanooga	Catoosa	GA	11.60	0.01	18	63.7%
13083	Chattanooga	Dade	GA	11.01	0.00	16	67.9%
13295	Chattanooga	Walker	GA	0.00	0.01	9	0.1%
17031	Chicago	Cook	IL	608.24	164.40	1,362	56.7%
17043	Chicago	DuPage	IL	162.78	0.12	317	51.4%
17063	Chicago	Grundy	IL	13.20	5.01	42	43.5%
17089	Chicago	Kane	IL	59.50	0.09	138	43.3%
17093	Chicago	Kendall	IL	8.18	0.01	27	30.5%
17097	Chicago	Lake	IL	30.80	19.13	138	36.2%
17111	Chicago	McHenry	IL	17.00	0.14	61	28.0%
17197	Chicago	Will	IL	163.07	3.70	242	68.9%
18089	Chicago	Lake	IN	132.19	12.15	232	62.3%
18127	Chicago	Porter	IN	40.84	10.56	85	60.4%
18029	Cincinnati	Dearborn	IN	5.59	17.59	35	65.7%
21015	Cincinnati	Boone	KY	7.99	26.40	54	63.8%
21037	Cincinnati	Campbell	KY	15.10	18.27	43	77.4%
21117	Cincinnati	Kenton	KY	29.20	9.12	59	65.4%
39017	Cincinnati	Butler	OH	40.67	0.04	92	44.2%
39025	Cincinnati	Clermont	OH	1.76	34.82	63	58.0%
39061	Cincinnati	Hamilton	OH	39.70	103.13	268	53.3%
39165	Cincinnati	Warren	OH	6.08	0.08	49	12.5%
39007	Cleveland	Ashtabula	OH	27.38	138.54	185	89.5%
39035	Cleveland	Cuyahoga	OH	76.82	96.57	379	45.7%
39085	Cleveland	Lake	OH	18.90	21.00	71	56.4%
39093	Cleveland	Lorain	OH	45.04	88.60	190	70.4%
39103	Cleveland	Medina	OH	14.17	0.05	45	31.8%
39133	Cleveland	Portage	OH	28.09	0.21	61	46.1%
39153	Cleveland	Summit	OH	22.96	0.15	101	22.8%
26093	Detroit	Livingston	MI	2.33	0.06	35	6.8%
26099	Detroit	Macomb	MI	3.62	4.26	96	8.2%
26115	Detroit	Monroe	MI	17.08	6.95	60	39.7%
26125	Detroit	Oakland	MI	14.21	3.58	188	9.5%
26147	Detroit	St. Clair	MI	6.90	16.67	64	37.1%
26161	Detroit	Washtenaw	MI	3.82	0.04	61	6.3%
26163	Detroit	Wayne	MI	28.47	7.97	253	14.4%
48039	Houston	Brazoria	TX	17.74	191.47	248	84.2%
48071	Houston	Chambers	TX	1.01	5.88	16	44.1%
48157	Houston	Fort Bend	TX	24.70	0.08	79	31.5%
48167	Houston	Galveston	TX	12.47	438.65	487	92.6%
48201	Houston	Harris	TX	65.54	1,143.23	1,727	70.0%
48291	Houston	Liberty	TX	27.14	2.35	45	65.6%

FIPS	MSA	County	ST	2020 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
48339	Houston	Montgomery	TX	21.14	0.24	68	31.6%
48473	Houston	Waller	TX	6.14	0.04	15	42.5%
21019	Huntington	Boyd	KY	10.44	14.15	31	79.9%
21127	Huntington	Lawrence	KY	9.43	4.60	17	84.4%
39001	Huntington	Adams	OH	0.35	40.72	49	84.4%
39053	Huntington	Gallia	OH	3.09	17.90	28	73.8%
39087	Huntington	Lawrence	OH	11.20	26.58	44	85.6%
39145	Huntington	Scioto	OH	25.08	25.76	63	80.7%
54011	Huntington	Cabell	WV	22.84	19.57	54	78.0%
54053	Huntington	Mason	WV	5.31	30.79	47	76.4%
54099	Huntington	Wayne	WV	28.80	46.62	85	88.8%
18011	Indianapolis	Boone	IN	5.92	0.05	34	17.6%
18057	Indianapolis	Hamilton	IN	0.15	0.55	54	1.3%
18059	Indianapolis	Hancock	IN	4.58	0.03	28	16.2%
18063	Indianapolis	Hendricks	IN	16.27	0.03	55	29.9%
18081	Indianapolis	Johnson	IN	0.88	0.19	26	4.2%
18095	Indianapolis	Madison	IN	14.62	0.11	45	32.9%
18097	Indianapolis	Marion	IN	27.99	1.19	166	17.5%
18109	Indianapolis	Morgan	IN	0.40	0.20	19	3.1%
18145	Indianapolis	Shelby	IN	6.54	0.02	29	22.3%
20091	Kansas City	Johnson	KS	52.60	0.03	155	33.9%
20103	Kansas City	Leavenworth	KS	13.49	0.39	29	47.4%
20121	Kansas City	Miami	KS	77.03	0.14	92	83.9%
20209	Kansas City	Wyandotte	KS	28.47	3.46	56	57.5%
29037	Kansas City	Cass	MO	15.70	0.11	37	42.4%
29047	Kansas City	Clay	MO	26.78	3.48	64	47.6%
29049	Kansas City	Clinton	MO	0.00	0.14	12	1.2%
29095	Kansas City	Jackson	MO	85.15	25.94	223	49.8%
29107	Kansas City	Lafayette	MO	21.96	3.26	49	51.3%
29165	Kansas City	Platte	MO	21.42	0.67	51	42.9%
29177	Kansas City	Ray	MO	42.28	3.09	61	74.5%
6037	Los Angeles	Los Angeles	CA	217.08	1,290.10	2,697	55.9%
6059	Los Angeles	Orange	CA	56.50	136.94	729	26.6%
6065	Los Angeles	Riverside	CA	93.21	0.90	380	24.8%
6071	Los Angeles	San Bernardino	CA	321.96	0.42	574	56.2%
6111	Los Angeles	Ventura	CA	11.01	179.05	298	63.8%
27003	Minneapolis	Anoka	MN	19.93	10.06	72	41.9%
27019	Minneapolis	Carver	MN	0.05	0.67	20	3.6%
27037	Minneapolis	Dakota	MN	11.92	9.37	80	26.5%
27053	Minneapolis	Hennepin	MN	29.88	28.17	242	24.0%
27123	Minneapolis	Ramsey	MN	11.29	8.91	89	22.8%
27139	Minneapolis	Scott	MN	2.55	1.15	25	14.6%
27163	Minneapolis	Washington	MN	21.74	39.42	96	63.8%
9001	New York	Fairfield	CT	0.00	35.19	184	19.1%

FIPS	MSA	County	ST	2020 PM2.5			
				Diesel Locomotive	**Diesel Marine**	**Total Diesel Mobile**	**LM Percent**
9005	New York	Litchfield	CT	0.00	0.79	23	3.4%
34003	New York	Bergen	NJ	22.36	2.76	146	17.2%
34013	New York	Essex	NJ	5.18	0.79	95	6.3%
34017	New York	Hudson	NJ	19.90	21.74	120	34.7%
34019	New York	Hunterdon	NJ	7.47	0.29	41	19.0%
34023	New York	Middlesex	NJ	11.14	3.88	106	14.1%
34025	New York	Monmouth	NJ	6.84	23.33	114	26.6%
34027	New York	Morris	NJ	5.01	0.47	73	7.6%
34029	New York	Ocean	NJ	0.41	11.45	58	20.3%
34031	New York	Passaic	NJ	4.28	0.45	54	8.7%
34035	New York	Somerset	NJ	11.03	0.01	51	21.8%
34037	New York	Sussex	NJ	0.96	0.55	23	6.6%
34039	New York	Union	NJ	8.53	13.90	97	23.1%
36005	New York	Bronx	NY	0.12	0.62	75	1.0%
36047	New York	Kings	NY	0.00	1.07	146	0.7%
36059	New York	Nassau	NY	0.00	9.33	139	6.7%
36061	New York	New York	NY	0.00	0.44	364	0.1%
36071	New York	Orange	NY	8.01	2.02	63	15.9%
36081	New York	Queens	NY	0.06	1.66	228	0.8%
36085	New York	Richmond	NY	0.00	1.84	39	4.8%
36087	New York	Rockland	NY	6.33	2.13	37	22.9%
36103	New York	Suffolk	NY	0.00	32.24	193	16.7%
36119	New York	Westchester	NY	0.00	3.02	123	2.5%
10003	Philadelphia	New Castle	DE	23.49	36.76	144	41.7%
24015	Philadelphia	Cecil	MD	7.73	1.40	30	30.2%
24029	Philadelphia	Kent	MD	0.06	1.21	12	10.5%
24031	Philadelphia	Montgomery	MD	21.88	0.43	127	17.6%
34005	Philadelphia	Burlington	NJ	0.00	42.25	100	42.2%
34007	Philadelphia	Camden	NJ	3.47	16.92	72	28.3%
34011	Philadelphia	Cumberland	NJ	0.55	43.19	65	67.8%
34015	Philadelphia	Gloucester	NJ	0.83	22.64	63	37.2%
34021	Philadelphia	Mercer	NJ	4.55	5.17	64	15.3%
34033	Philadelphia	Salem	NJ	0.25	13.18	28	47.6%
42017	Philadelphia	Bucks	PA	1.95	1.00	78	3.8%
42029	Philadelphia	Chester	PA	9.26	0.14	81	11.7%
42045	Philadelphia	Delaware	PA	3.76	149.53	199	77.0%
42101	Philadelphia	Philadelphia	PA	5.74	262.48	383	69.9%
4013	Phoenix	Maricopa	AZ	89.13	0.69	709	12.7%
4021	Phoenix	Pinal	AZ	48.94	0.15	92	53.5%
6019	San Joaquin	Fresno	CA	15.98	0.51	236	7.0%
6029	San Joaquin	Kern	CA	80.81	0.19	265	30.6%
6031	San Joaquin	Kings	CA	2.13	0.02	56	3.8%
6039	San Joaquin	Madera	CA	17.29	0.14	63	27.9%
6047	San Joaquin	Merced	CA	15.33	0.40	84	18.6%
6077	San Joaquin	San Joaquin	CA	26.62	23.51	184	27.3%

FIPS	MSA	County	ST	2020 PM2.5 Diesel Locomotive	2020 PM2.5 Diesel Marine	2020 PM2.5 Total Diesel Mobile	2020 PM2.5 LM Percent
6099	San Joaquin	Stanislaus	CA	10.69	0.21	101	10.8%
6107	San Joaquin	Tulare	CA	24.00	0.14	133	18.1%
53029	Seattle	Island	WA	0.00	15.26	25	60.2%
53033	Seattle	King	WA	27.06	149.20	484	36.4%
53035	Seattle	Kitsap	WA	0.00	1.13	27	4.2%
53045	Seattle	Mason	WA	0.00	0.50	7	7.1%
53053	Seattle	Pierce	WA	16.97	134.63	238	63.7%
53061	Seattle	Snohomish	WA	33.68	23.01	140	40.4%
53067	Seattle	Thurston	WA	9.33	9.42	48	39.1%
17027	St. Louis	Clinton	IL	21.27	0.07	41	51.8%
17083	St. Louis	Jersey	IL	1.73	14.76	28	57.9%
17119	St. Louis	Madison	IL	8.44	8.01	67	24.7%
17133	St. Louis	Monroe	IL	33.99	12.95	60	77.8%
17163	St. Louis	St. Clair	IL	9.49	15.31	69	36.2%
29055	St. Louis	Crawford	MO	4.54	0.04	12	38.8%
29071	St. Louis	Franklin	MO	29.11	1.86	54	57.6%
29099	St. Louis	Jefferson	MO	7.90	13.13	49	43.3%
29113	St. Louis	Lincoln	MO	13.04	5.22	34	53.8%
29183	St. Louis	St. Charles	MO	15.70	11.75	73	37.4%
29189	St. Louis	St. Louis	MO	25.09	15.01	214	18.8%
29219	St. Louis	Warren	MO	2.66	1.81	14	32.7%
29510	St. Louis	St. Louis	MO	22.18	202.23	256	87.7%

Table 0-108 2030 Locomotive and Diesel Marine PM2.5 Tons/Year and Percent of Total Diesel Mobile Sources

FIPS	MSA	County	ST	2030 PM2.5 Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
13013	Atlanta	Barrow	GA	5.25	0.01	9	60.3%
13015	Atlanta	Bartow	GA	18.79	0.20	28	68.0%
13045	Atlanta	Carroll	GA	5.08	0.08	14	37.1%
13057	Atlanta	Cherokee	GA	0.00	0.19	14	1.3%
13063	Atlanta	Clayton	GA	9.90	0.03	27	36.7%
13067	Atlanta	Cobb	GA	25.96	0.08	85	30.8%
13077	Atlanta	Coweta	GA	13.06	0.06	25	53.1%
13089	Atlanta	DeKalb	GA	12.03	0.05	66	18.2%
13097	Atlanta	Douglas	GA	4.66	0.01	12	40.2%
13113	Atlanta	Fayette	GA	3.37	0.04	13	26.9%
13117	Atlanta	Forsyth	GA	0.00	0.40	14	2.9%
13121	Atlanta	Fulton	GA	35.38	0.11	130	27.4%
13135	Atlanta	Gwinnett	GA	8.98	0.07	69	13.2%
13139	Atlanta	Hall	GA	5.34	0.65	21	29.0%
13149	Atlanta	Heard	GA	0.00	0.09	1	8.2%
13151	Atlanta	Henry	GA	13.32	0.04	28	47.3%
13217	Atlanta	Newton	GA	1.50	0.05	9	16.7%
13223	Atlanta	Paulding	GA	11.04	0.03	19	58.6%
13237	Atlanta	Putnam	GA	0.29	0.30	2	26.8%
13247	Atlanta	Rockdale	GA	2.14	0.03	10	22.0%
13255	Atlanta	Spalding	GA	0.57	0.03	6	10.2%
13297	Atlanta	Walton	GA	1.81	0.01	6	28.3%
24003	Baltimore	Anne Arundel	MD	9.01	1.77	43	24.8%
24005	Baltimore	Baltimore	MD	32.54	1.15	94	36.0%
24013	Baltimore	Carroll	MD	5.05	0.04	22	23.1%
24025	Baltimore	Harford	MD	8.01	1.11	28	32.2%
24027	Baltimore	Howard	MD	11.21	0.35	35	33.5%
24510	Baltimore	Baltimore	MD	45.29	259.26	330	92.2%
1073	Birmingham	Jefferson	AL	72.52	0.94	143	51.5%
1117	Birmingham	Shelby	AL	38.03	0.29	52	73.3%
1127	Birmingham	Walker	AL	14.10	0.93	26	58.7%
9007	Boston	Middlesex	CT	0.00	1.70	14	12.3%
25001	Boston	Barnstable	MA	5.94	18.19	42	58.0%
25005	Boston	Bristol	MA	11.25	12.53	55	43.6%
25007	Boston	Dukes	MA	0.00	111.06	112	98.9%
25009	Boston	Essex	MA	14.59	4.59	63	30.3%
25019	Boston	Nantucket	MA	0.00	16.73	18	93.2%
25021	Boston	Norfolk	MA	17.74	5.72	72	32.7%
25023	Boston	Plymouth	MA	9.26	4.83	42	33.7%
25025	Boston	Suffolk	MA	9.40	47.81	295	19.4%
25027	Boston	Worcester	MA	35.83	1.04	91	40.4%
33011	Boston	Hillsborough	NH	1.09	0.42	31	4.9%

FIPS	MSA	County	ST	2030 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
33015	Boston	Rockingham	NH	0.82	30.13	56	55.2%
47065	Chattanooga	Hamilton	TN	36.91	24.61	85	72.5%
47115	Chattanooga	Marion	TN	5.16	4.78	15	67.1%
47153	Chattanooga	Sequatchie	TN	0.00	0.00	1	0.0%
13047	Chattanooga	Catoosa	GA	11.18	0.01	15	74.0%
13083	Chattanooga	Dade	GA	10.61	0.00	14	76.7%
13295	Chattanooga	Walker	GA	0.00	0.01	5	0.1%
17031	Chicago	Cook	IL	583.11	176.82	1,069	71.1%
17043	Chicago	DuPage	IL	150.13	0.14	227	66.1%
17063	Chicago	Grundy	IL	12.86	5.35	29	62.4%
17089	Chicago	Kane	IL	55.63	0.10	91	61.3%
17093	Chicago	Kendall	IL	7.87	0.01	16	48.2%
17097	Chicago	Lake	IL	28.70	21.57	96	52.5%
17111	Chicago	McHenry	IL	15.86	0.16	37	42.9%
17197	Chicago	Will	IL	154.37	3.97	195	81.2%
18089	Chicago	Lake	IN	129.63	13.55	186	77.1%
18127	Chicago	Porter	IN	39.03	11.74	68	75.0%
18029	Cincinnati	Dearborn	IN	5.39	18.81	30	79.5%
21015	Cincinnati	Boone	KY	7.70	28.23	46	78.5%
21037	Cincinnati	Campbell	KY	14.53	19.53	40	85.6%
21117	Cincinnati	Kenton	KY	28.15	9.75	49	78.1%
39017	Cincinnati	Butler	OH	38.73	0.05	64	60.4%
39025	Cincinnati	Clermont	OH	1.68	37.21	53	72.9%
39061	Cincinnati	Hamilton	OH	38.03	110.20	216	68.7%
39165	Cincinnati	Warren	OH	5.88	0.09	26	23.0%
39007	Cleveland	Ashtabula	OH	26.16	148.22	185	94.4%
39035	Cleveland	Cuyahoga	OH	73.82	103.97	280	63.4%
39085	Cleveland	Lake	OH	17.97	22.85	57	71.2%
39093	Cleveland	Lorain	OH	42.97	94.99	165	83.8%
39103	Cleveland	Medina	OH	13.67	0.06	30	45.8%
39133	Cleveland	Portage	OH	26.81	0.24	45	60.8%
39153	Cleveland	Summit	OH	21.98	0.17	63	35.3%
26093	Detroit	Livingston	MI	2.25	0.06	20	11.7%
26099	Detroit	Macomb	MI	3.49	4.61	56	14.6%
26115	Detroit	Monroe	MI	16.47	7.45	42	56.9%
26125	Detroit	Oakland	MI	13.69	3.84	108	16.2%
26147	Detroit	St. Clair	MI	6.63	17.88	44	55.4%
26161	Detroit	Washtenaw	MI	3.80	0.04	35	11.1%
26163	Detroit	Wayne	MI	29.36	8.63	151	25.1%
48039	Houston	Brazoria	TX	17.11	204.68	242	91.5%
48071	Houston	Chambers	TX	0.97	6.36	12	59.3%
48157	Houston	Fort Bend	TX	23.77	0.09	52	45.9%
48167	Houston	Galveston	TX	13.22	468.88	500	96.4%
48201	Houston	Harris	TX	67.89	1,221.64	1,557	82.8%
48291	Houston	Liberty	TX	26.15	2.52	37	77.9%

FIPS	MSA	County	ST	2030 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
48339	Houston	Montgomery	TX	20.38	0.27	49	42.2%
48473	Houston	Waller	TX	5.92	0.04	10	58.2%
21019	Huntington	Boyd	KY	10.05	15.13	29	87.4%
21127	Huntington	Lawrence	KY	8.93	4.91	15	90.7%
39001	Huntington	Adams	OH	0.34	43.51	48	92.1%
39053	Huntington	Gallia	OH	2.94	19.13	26	85.9%
39087	Huntington	Lawrence	OH	10.68	28.40	43	91.2%
39145	Huntington	Scioto	OH	23.91	27.52	58	89.0%
54011	Huntington	Cabell	WV	21.94	20.93	49	86.9%
54053	Huntington	Mason	WV	5.03	32.92	42	89.3%
54099	Huntington	Wayne	WV	27.75	49.83	82	95.0%
18011	Indianapolis	Boone	IN	5.59	0.06	19	30.0%
18057	Indianapolis	Hamilton	IN	0.18	0.63	26	3.1%
18059	Indianapolis	Hancock	IN	4.35	0.03	16	28.1%
18063	Indianapolis	Hendricks	IN	15.52	0.03	33	46.7%
18081	Indianapolis	Johnson	IN	1.02	0.21	14	8.9%
18095	Indianapolis	Madison	IN	13.96	0.12	29	47.9%
18097	Indianapolis	Marion	IN	26.79	1.35	98	28.7%
18109	Indianapolis	Morgan	IN	0.46	0.22	10	6.6%
18145	Indianapolis	Shelby	IN	6.23	0.02	17	36.6%
20091	Kansas City	Johnson	KS	50.70	0.04	101	50.4%
20103	Kansas City	Leavenworth	KS	13.00	0.42	21	63.9%
20121	Kansas City	Miami	KS	74.26	0.15	81	91.7%
20209	Kansas City	Wyandotte	KS	27.42	3.70	43	71.6%
29037	Kansas City	Cass	MO	15.11	0.12	26	59.1%
29047	Kansas City	Clay	MO	27.23	3.74	48	64.9%
29049	Kansas City	Clinton	MO	0.00	0.16	6	2.9%
29095	Kansas City	Jackson	MO	85.76	27.74	171	66.5%
29107	Kansas City	Lafayette	MO	21.17	3.50	36	68.5%
29165	Kansas City	Platte	MO	20.65	0.74	35	61.6%
29177	Kansas City	Ray	MO	42.32	3.31	53	86.7%
6037	Los Angeles	Los Angeles	CA	214.05	1,378.65	2,053	77.6%
6059	Los Angeles	Orange	CA	57.93	146.38	433	47.2%
6065	Los Angeles	Riverside	CA	87.56	1.02	189	46.8%
6071	Los Angeles	San Bernardino	CA	306.89	0.48	400	76.8%
6111	Los Angeles	Ventura	CA	10.79	191.39	247	81.7%
27003	Minneapolis	Anoka	MN	19.16	10.87	51	59.0%
27019	Minneapolis	Carver	MN	0.05	0.75	10	7.6%
27037	Minneapolis	Dakota	MN	11.47	10.11	51	42.4%
27053	Minneapolis	Hennepin	MN	28.80	30.34	153	38.7%
27123	Minneapolis	Ramsey	MN	10.87	9.61	56	36.4%
27139	Minneapolis	Scott	MN	2.46	1.27	14	26.4%
27163	Minneapolis	Washington	MN	20.93	42.22	81	78.3%
9001	New York	Fairfield	CT	0.00	37.87	112	33.7%

FIPS	MSA	County	ST	2030 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
9005	New York	Litchfield	CT	0.00	0.90	13	6.6%
34003	New York	Bergen	NJ	20.91	2.98	89	26.9%
34013	New York	Essex	NJ	4.68	0.85	50	11.0%
34017	New York	Hudson	NJ	18.73	23.28	79	53.1%
34019	New York	Hunterdon	NJ	6.78	0.33	25	28.1%
34023	New York	Middlesex	NJ	10.49	4.17	63	23.1%
34025	New York	Monmouth	NJ	5.78	25.21	75	41.6%
34027	New York	Morris	NJ	4.44	0.53	42	11.9%
34029	New York	Ocean	NJ	0.36	12.87	39	33.6%
34031	New York	Passaic	NJ	3.75	0.51	30	14.0%
34035	New York	Somerset	NJ	10.24	0.02	32	32.2%
34037	New York	Sussex	NJ	1.10	0.63	13	12.9%
34039	New York	Union	NJ	7.68	14.86	59	38.2%
36005	New York	Bronx	NY	0.12	0.69	38	2.1%
36047	New York	Kings	NY	0.00	1.18	77	1.5%
36059	New York	Nassau	NY	0.00	10.10	78	12.9%
36061	New York	New York	NY	0.00	0.48	168	0.3%
36071	New York	Orange	NY	7.53	2.18	39	25.2%
36081	New York	Queens	NY	0.05	1.83	103	1.8%
36085	New York	Richmond	NY	0.00	2.00	19	10.3%
36087	New York	Rockland	NY	6.09	2.31	23	36.8%
36103	New York	Suffolk	NY	0.00	35.49	118	30.1%
36119	New York	Westchester	NY	0.00	3.29	61	5.4%
10003	Philadelphia	New Castle	DE	23.04	39.30	105	59.6%
24015	Philadelphia	Cecil	MD	7.20	1.55	20	43.2%
24029	Philadelphia	Kent	MD	0.06	1.36	6	22.2%
24031	Philadelphia	Montgomery	MD	19.61	0.46	78	25.7%
34005	Philadelphia	Burlington	NJ	0.00	45.18	76	59.6%
34007	Philadelphia	Camden	NJ	3.05	18.09	49	43.0%
34011	Philadelphia	Cumberland	NJ	0.64	46.39	58	81.6%
34015	Philadelphia	Gloucester	NJ	0.83	24.22	45	55.3%
34021	Philadelphia	Mercer	NJ	4.21	5.53	38	25.5%
34033	Philadelphia	Salem	NJ	0.26	14.13	22	65.7%
42017	Philadelphia	Bucks	PA	1.82	1.10	44	6.7%
42029	Philadelphia	Chester	PA	8.44	0.16	46	18.8%
42045	Philadelphia	Delaware	PA	3.48	159.80	188	86.8%
42101	Philadelphia	Philadelphia	PA	5.93	280.49	347	82.6%
4013	Phoenix	Maricopa	AZ	85.15	0.79	425	20.2%
4021	Phoenix	Pinal	AZ	46.98	0.17	71	66.3%
6019	San Joaquin	Fresno	CA	15.23	0.58	101	15.7%
6029	San Joaquin	Kern	CA	76.62	0.22	145	52.9%
6031	San Joaquin	Kings	CA	1.98	0.02	21	9.3%
6039	San Joaquin	Madera	CA	16.55	0.16	32	52.1%
6047	San Joaquin	Merced	CA	14.48	0.46	41	36.8%
6077	San Joaquin	San Joaquin	CA	25.33	25.14	100	50.3%

FIPS	MSA	County	ST	2030 PM2.5			
				Diesel Locomotive	Diesel Marine	Total Diesel Mobile	LM Percent
6099	San Joaquin	Stanislaus	CA	10.15	0.23	45	23.3%
6107	San Joaquin	Tulare	CA	22.89	0.16	65	35.4%
53029	Seattle	Island	WA	0.00	16.34	22	75.7%
53033	Seattle	King	WA	26.00	159.80	344	54.0%
53035	Seattle	Kitsap	WA	0.00	1.28	16	8.1%
53045	Seattle	Mason	WA	0.00	0.57	4	12.8%
53053	Seattle	Pierce	WA	16.30	144.03	206	77.8%
53061	Seattle	Snohomish	WA	32.24	24.77	102	56.0%
53067	Seattle	Thurston	WA	8.81	10.12	36	53.2%
17027	St. Louis	Clinton	IL	20.38	0.08	29	69.4%
17083	St. Louis	Jersey	IL	1.66	15.78	23	76.4%
17119	St. Louis	Madison	IL	8.64	8.56	43	40.3%
17133	St. Louis	Monroe	IL	32.45	13.84	52	88.4%
17163	St. Louis	St. Clair	IL	9.36	16.36	48	53.5%
29055	St. Louis	Crawford	MO	4.30	0.04	9	50.9%
29071	St. Louis	Franklin	MO	27.96	2.00	43	70.5%
29099	St. Louis	Jefferson	MO	7.62	14.04	38	57.1%
29113	St. Louis	Lincoln	MO	12.57	5.60	26	70.5%
29183	St. Louis	St. Charles	MO	15.14	12.62	51	54.2%
29189	St. Louis	St. Louis	MO	24.13	16.08	130	30.9%
29219	St. Louis	Warren	MO	2.56	1.95	9	49.3%
29510	St. Louis	St. Louis	MO	23.99	216.11	260	92.3%

Table 0-109 2002 Locomotive and Diesel Marine NOx Tons/Year and Percent of Total Mobile Sources

FIPS	MSA	County	ST	2002 NOx Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
13013	Atlanta	Barrow	GA	224.1	0.5	2,039	11.0%
13015	Atlanta	Bartow	GA	799.6	7.0	5,172	15.6%
13045	Atlanta	Carroll	GA	219.5	3.0	4,762	4.7%
13057	Atlanta	Cherokee	GA	0.0	6.8	5,828	0.1%
13063	Atlanta	Clayton	GA	420.9	1.0	9,512	4.4%
13067	Atlanta	Cobb	GA	1,110.1	2.8	23,542	4.7%
13077	Atlanta	Coweta	GA	555.6	2.0	5,727	9.7%
13089	Atlanta	DeKalb	GA	515.4	1.8	26,283	2.0%
13097	Atlanta	Douglas	GA	202.2	0.5	3,952	5.1%
13113	Atlanta	Fayette	GA	143.8	1.3	3,977	3.6%
13117	Atlanta	Forsyth	GA	0.0	14.1	4,418	0.3%
13121	Atlanta	Fulton	GA	1,512.7	3.8	39,991	3.8%
13135	Atlanta	Gwinnett	GA	385.8	2.5	21,343	1.8%
13139	Atlanta	Hall	GA	258.8	23.1	6,452	4.4%
13149	Atlanta	Heard	GA	0.0	3.3	465	0.7%
13151	Atlanta	Henry	GA	567.2	1.3	6,479	8.8%
13217	Atlanta	Newton	GA	64.4	1.8	3,584	1.8%
13223	Atlanta	Paulding	GA	470.2	1.0	3,801	12.4%
13237	Atlanta	Putnam	GA	14.1	10.6	630	3.9%
13247	Atlanta	Rockdale	GA	91.1	1.0	3,158	2.9%
13255	Atlanta	Spalding	GA	24.5	1.0	2,584	1.0%
13297	Atlanta	Walton	GA	77.1	0.5	2,211	3.5%
24003	Baltimore	Anne Arundel	MD	520.4	63.4	15,497	3.8%
24005	Baltimore	Baltimore	MD	1,243.0	41.5	24,021	5.3%
24013	Baltimore	Carroll	MD	199.2	1.3	5,995	3.3%
24025	Baltimore	Harford	MD	389.4	40.2	7,894	5.4%
24027	Baltimore	Howard	MD	594.5	12.7	8,160	7.4%
24510	Baltimore	Baltimore	MD	1,282.5	1,670.4	23,591	12.5%
1073	Birmingham	Jefferson	AL	4,615.9	268.9	32,416	15.1%
1117	Birmingham	Shelby	AL	1,156.1	10.4	6,159	18.9%
1127	Birmingham	Walker	AL	889.2	116.8	3,687	27.3%
9007	Boston	Middlesex	CT	160.2	121.4	282	99.8%
25001	Boston	Barnstable	MA	318.1	474.3	8,446	9.4%
25005	Boston	Bristol	MA	588.4	238.7	15,719	5.3%
25007	Boston	Dukes	MA	0.0	1,589.6	2,042	77.9%
25009	Boston	Essex	MA	777.6	197.2	21,303	4.6%
25019	Boston	Nantucket	MA	0.0	282.5	596	47.4%
25021	Boston	Norfolk	MA	902.6	163.4	22,498	4.7%
25023	Boston	Plymouth	MA	493.8	169.6	12,655	5.2%
25025	Boston	Suffolk	MA	489.2	855.0	38,095	3.5%
25027	Boston	Worcester	MA	1,860.6	36.5	26,614	7.1%
33011	Boston	Hillsborough	NH	49.0	15.0	12,444	0.5%
33015	Boston	Rockingham	NH	37.0	1,112.9	11,846	9.7%

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
47065	Chattanooga	Hamilton	TN	1,569.2	909.5	14,329	17.3%
47115	Chattanooga	Marion	TN	220.0	176.6	2,998	13.2%
47153	Chattanooga	Sequatchie	TN	0.0	0.0	270	0.0%
13047	Chattanooga	Catoosa	GA	475.9	0.3	2,527	18.8%
13083	Chattanooga	Dade	GA	452.1	0.0	2,263	20.0%
13295	Chattanooga	Walker	GA	0.0	0.3	1,996	0.0%
17031	Chicago	Cook	IL	24,769.1	6,520.5	178,269	17.6%
17043	Chicago	DuPage	IL	7,028.5	5.0	31,241	22.5%
17063	Chicago	Grundy	IL	479.6	198.0	3,244	20.9%
17089	Chicago	Kane	IL	2,446.9	3.5	8,879	27.6%
17093	Chicago	Kendall	IL	310.8	0.3	1,789	17.4%
17097	Chicago	Lake	IL	1,301.3	774.4	16,423	12.6%
17111	Chicago	McHenry	IL	700.7	5.8	5,103	13.8%
17197	Chicago	Will	IL	6,401.5	146.5	16,000	40.9%
18089	Chicago	Lake	IN	4,656.8	490.6	23,491	21.9%
18127	Chicago	Porter	IN	1,588.7	425.4	8,840	22.8%
18029	Cincinnati	Dearborn	IN	216.3	696.0	3,628	25.1%
21015	Cincinnati	Boone	KY	327.3	1,044.5	5,966	23.0%
21037	Cincinnati	Campbell	KY	621.1	722.6	4,914	27.3%
21117	Cincinnati	Kenton	KY	1,197.5	360.8	7,316	21.3%
39017	Cincinnati	Butler	OH	1,581.9	1.7	10,604	14.9%
39025	Cincinnati	Clermont	OH	68.2	1,377.2	7,579	19.1%
39061	Cincinnati	Hamilton	OH	1,540.5	4,078.9	34,403	16.3%
39165	Cincinnati	Warren	OH	235.3	3.2	5,948	4.0%
39007	Cleveland	Ashtabula	OH	1,062.3	5,482.2	12,796	51.1%
39035	Cleveland	Cuyahoga	OH	2,914.2	3,832.5	49,767	13.6%
39085	Cleveland	Lake	OH	738.0	837.5	8,866	17.8%
39093	Cleveland	Lorain	OH	1,749.1	3,509.5	15,702	33.5%
39103	Cleveland	Medina	OH	551.8	2.1	6,896	8.0%
39133	Cleveland	Portage	OH	1,090.9	8.6	8,119	13.5%
39153	Cleveland	Summit	OH	888.7	6.0	18,330	4.9%
26093	Detroit	Livingston	MI	95.5	1.9	7,393	1.3%
26099	Detroit	Macomb	MI	148.2	169.4	24,046	1.3%
26115	Detroit	Monroe	MI	700.2	276.4	7,675	12.7%
26125	Detroit	Oakland	MI	584.1	140.9	38,601	1.9%
26147	Detroit	St. Clair	MI	285.7	662.4	9,871	9.6%
26161	Detroit	Washtenaw	MI	154.9	1.3	12,742	1.2%
26163	Detroit	Wayne	MI	1,133.9	318.6	68,502	2.1%
48039	Houston	Brazoria	TX	728.4	7,573.7	18,133	45.8%
48071	Houston	Chambers	TX	41.6	234.3	2,586	10.7%
48157	Houston	Fort Bend	TX	1,019.2	3.3	11,057	9.2%
48167	Houston	Galveston	TX	491.0	17,352.7	30,023	59.4%
48201	Houston	Harris	TX	2,609.1	45,215.7	165,530	28.9%
48291	Houston	Liberty	TX	1,115.9	93.4	4,073	29.7%
48339	Houston	Montgomery	TX	867.4	9.7	13,754	6.4%
48473	Houston	Waller	TX	252.5	1.5	1,574	16.1%

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
21019	Huntington	Boyd	KY	430.5	559.8	3,171	31.2%
21127	Huntington	Lawrence	KY	425.1	181.8	1,317	46.1%
39001	Huntington	Adams	OH	13.7	1,610.6	3,248	50.0%
39053	Huntington	Gallia	OH	119.7	708.1	2,184	37.9%
39087	Huntington	Lawrence	OH	433.9	1,051.2	3,946	37.6%
39145	Huntington	Scioto	OH	972.1	1,018.7	4,780	41.7%
54011	Huntington	Cabell	WV	946.3	774.1	9,978	17.2%
54053	Huntington	Mason	WV	239.7	1,218.0	2,909	50.1%
54099	Huntington	Wayne	WV	1,182.1	1,844.2	4,489	67.4%
18011	Indianapolis	Boone	IN	235.9	2.1	3,600	6.6%
18057	Indianapolis	Hamilton	IN	5.7	22.6	7,413	0.4%
18059	Indianapolis	Hancock	IN	179.7	1.2	3,342	5.4%
18063	Indianapolis	Hendricks	IN	630.8	1.2	5,968	10.6%
18081	Indianapolis	Johnson	IN	33.0	7.6	4,964	0.8%
18095	Indianapolis	Madison	IN	563.4	4.3	6,314	9.0%
18097	Indianapolis	Marion	IN	1,089.8	48.3	33,822	3.4%
18109	Indianapolis	Morgan	IN	15.0	8.0	3,634	0.6%
18145	Indianapolis	Shelby	IN	255.6	0.9	3,130	8.2%
20091	Kansas City	Johnson	KS	2,157.3	1.4	18,312	11.8%
20103	Kansas City	Leavenworth	KS	553.1	15.5	2,984	19.1%
20121	Kansas City	Miami	KS	3,157.4	5.5	4,481	70.6%
20209	Kansas City	Wyandotte	KS	1,170.2	137.0	7,329	17.8%
29037	Kansas City	Cass	MO	646.8	4.4	3,752	17.4%
29047	Kansas City	Clay	MO	1,073.0	137.9	8,204	14.8%
29049	Kansas City	Clinton	MO	0.0	5.8	1,517	0.4%
29095	Kansas City	Jackson	MO	3,434.0	1,026.2	30,133	14.8%
29107	Kansas City	Lafayette	MO	899.9	129.2	3,796	27.1%
29165	Kansas City	Platte	MO	878.0	26.9	5,793	15.6%
29177	Kansas City	Ray	MO	1,713.2	122.5	3,190	57.5%
6037	Los Angeles	Los Angeles	CA	9,771.2	42,754.8	257,574	20.4%
6059	Los Angeles	Orange	CA	2,374.1	2,363.7	68,174	6.9%
6065	Los Angeles	Riverside	CA	4,414.1	56.3	45,019	9.9%
6071	Los Angeles	San Bernardino	CA	14,261.8	26.3	56,392	25.3%
6111	Los Angeles	Ventura	CA	479.2	4,087.6	18,815	24.3%
27003	Minneapolis	Anoka	MN	822.8	399.5	10,508	11.6%
27019	Minneapolis	Carver	MN	2.0	27.0	2,563	1.1%
27037	Minneapolis	Dakota	MN	491.2	371.9	11,559	7.5%
27053	Minneapolis	Hennepin	MN	1,226.2	1,117.3	42,042	5.6%
27123	Minneapolis	Ramsey	MN	465.4	353.7	18,199	4.5%
27139	Minneapolis	Scott	MN	104.5	46.1	2,947	5.1%
27163	Minneapolis	Washington	MN	895.5	1,560.4	9,536	25.8%
9001	New York	Fairfield	CT	589.7	257.5	28,368	3.0%
9005	New York	Litchfield	CT	100.0	31.6	4,615	2.9%
34003	New York	Bergen	NJ	1,055.1	193.9	23,136	5.4%
34013	New York	Essex	NJ	228.1	51.3	21,624	1.3%

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
34017	New York	Hudson	NJ	777.7	1,486.3	16,558	13.7%
34019	New York	Hunterdon	NJ	331.3	11.7	7,327	4.7%
34023	New York	Middlesex	NJ	481.9	282.2	19,497	3.9%
34025	New York	Monmouth	NJ	379.8	682.3	17,750	6.0%
34027	New York	Morris	NJ	234.4	18.7	13,461	1.9%
34029	New York	Ocean	NJ	19.6	435.6	12,234	3.7%
34031	New York	Passaic	NJ	229.2	18.1	11,334	2.2%
34035	New York	Somerset	NJ	509.9	0.6	8,259	6.2%
34037	New York	Sussex	NJ	36.0	22.2	4,546	1.3%
34039	New York	Union	NJ	420.7	1,084.1	14,897	10.1%
36005	New York	Bronx	NY	5.1	203.9	18,301	1.1%
36047	New York	Kings	NY	0.0	1,713.6	36,548	4.7%
36059	New York	Nassau	NY	0.0	586.4	22,268	2.6%
36061	New York	New York	NY	0.0	1,207.0	44,035	2.7%
36071	New York	Orange	NY	349.9	80.2	13,475	3.2%
36081	New York	Queens	NY	2.3	2,056.4	39,760	5.2%
36085	New York	Richmond	NY	0.0	2,386.5	8,667	27.5%
36087	New York	Rockland	NY	265.0	16.6	4,886	5.8%
36103	New York	Suffolk	NY	0.0	1,361.4	27,455	5.0%
36119	New York	Westchester	NY	0.0	127.5	16,193	0.8%
10003	Philadelphia	New Castle	DE	818.9	2,545.5	21,119	15.9%
24015	Philadelphia	Cecil	MD	306.8	56.0	5,150	7.0%
24029	Philadelphia	Kent	MD	2.4	48.8	984	5.2%
24031	Philadelphia	Montgomery	MD	987.2	16.9	23,771	4.2%
34005	Philadelphia	Burlington	NJ	0.0	1,178.2	13,449	8.8%
34007	Philadelphia	Camden	NJ	182.3	471.7	13,996	4.7%
34011	Philadelphia	Cumberland	NJ	20.8	1,242.9	5,472	23.1%
34015	Philadelphia	Gloucester	NJ	36.7	633.3	10,121	6.6%
34021	Philadelphia	Mercer	NJ	193.5	144.7	12,609	2.7%
34033	Philadelphia	Salem	NJ	10.3	374.9	3,009	12.8%
42017	Philadelphia	Bucks	PA	86.8	40.0	13,732	0.9%
42029	Philadelphia	Chester	PA	435.2	5.7	12,150	3.6%
42045	Philadelphia	Delaware	PA	171.7	5,914.4	18,361	33.1%
42101	Philadelphia	Philadelphia	PA	239.6	10,381.6	44,901	23.7%
4013	Phoenix	Maricopa	AZ	3,884.9	28.0	105,636	3.7%
4021	Phoenix	Pinal	AZ	2,030.8	6.2	10,844	18.8%
6019	San Joaquin	Fresno	CA	765.2	32.2	24,853	3.2%
6029	San Joaquin	Kern	CA	3,687.8	12.0	27,768	13.3%
6031	San Joaquin	Kings	CA	104.0	1.1	4,389	2.4%
6039	San Joaquin	Madera	CA	819.3	8.9	5,469	15.1%
6047	San Joaquin	Merced	CA	790.7	25.4	9,353	8.7%
6077	San Joaquin	San Joaquin	CA	1,287.6	603.0	18,977	10.0%
6099	San Joaquin	Stanislaus	CA	528.7	12.5	12,862	4.2%
6107	San Joaquin	Tulare	CA	1,172.3	8.9	13,310	8.9%
53029	Seattle	Island	WA	0.0	2,098.3	3,999	52.5%
53033	Seattle	King	WA	1,119.6	5,906.0	68,488	10.3%

FIPS	MSA	County	ST	2002 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
53035	Seattle	Kitsap	WA	0.0	45.6	6,933	0.7%
53045	Seattle	Mason	WA	0.1	26.7	1,679	1.6%
53053	Seattle	Pierce	WA	703.0	5,327.1	27,443	22.0%
53061	Seattle	Snohomish	WA	1,279.7	912.6	20,798	10.5%
53067	Seattle	Thurston	WA	369.2	373.3	8,518	8.7%
17027	St. Louis	Clinton	IL	801.1	2.8	2,597	31.0%
17083	St. Louis	Jersey	IL	64.8	583.9	1,759	36.9%
17119	St. Louis	Madison	IL	287.0	316.7	10,200	5.9%
17133	St. Louis	Monroe	IL	1,288.0	512.0	3,122	57.7%
17163	St. Louis	St. Clair	IL	325.2	605.6	10,049	9.3%
29055	St. Louis	Crawford	MO	204.7	1.5	2,080	9.9%
29071	St. Louis	Franklin	MO	1,206.1	73.8	6,434	19.9%
29099	St. Louis	Jefferson	MO	324.2	519.4	9,205	9.2%
29113	St. Louis	Lincoln	MO	534.3	206.8	2,771	26.7%
29183	St. Louis	St. Charles	MO	643.6	465.6	10,406	10.7%
29189	St. Louis	St. Louis	MO	1,035.3	594.2	41,254	4.0%
29219	St. Louis	Warren	MO	109.1	71.9	1,692	10.7%
29510	St. Louis	St. Louis	MO	866.5	7,998.7	23,595	37.6%

Table 0-110 2020 Locomotive and Diesel Marine NOx Tons/Year and Percent of Total Mobile Sources

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
13013	Atlanta	Barrow	GA	189.4	0.6	682	27.9%
13015	Atlanta	Bartow	GA	675.7	8.5	1,838	37.2%
13045	Atlanta	Carroll	GA	183.4	3.6	1,404	13.3%
13057	Atlanta	Cherokee	GA	0.0	8.1	1,834	0.4%
13063	Atlanta	Clayton	GA	355.6	1.2	3,382	10.6%
13067	Atlanta	Cobb	GA	933.8	3.3	7,245	12.9%
13077	Atlanta	Coweta	GA	469.5	2.4	1,995	23.7%
13089	Atlanta	DeKalb	GA	433.1	2.1	7,494	5.8%
13097	Atlanta	Douglas	GA	168.0	0.6	1,353	12.5%
13113	Atlanta	Fayette	GA	121.5	1.5	1,333	9.2%
13117	Atlanta	Forsyth	GA	0.0	16.9	1,392	1.2%
13121	Atlanta	Fulton	GA	1,272.1	4.5	15,332	8.3%
13135	Atlanta	Gwinnett	GA	323.3	3.0	6,226	5.2%
13139	Atlanta	Hall	GA	186.3	27.8	1,919	11.2%
13149	Atlanta	Heard	GA	0.0	3.9	128	3.1%
13151	Atlanta	Henry	GA	479.3	1.5	2,241	21.5%
13217	Atlanta	Newton	GA	54.4	2.1	996	5.7%
13223	Atlanta	Paulding	GA	397.3	1.2	1,372	29.0%
13237	Atlanta	Putnam	GA	10.3	12.7	202	11.4%
13247	Atlanta	Rockdale	GA	77.0	1.2	1,026	7.6%
13255	Atlanta	Spalding	GA	20.7	1.2	728	3.0%
13297	Atlanta	Walton	GA	65.1	0.6	664	9.9%
24003	Baltimore	Anne Arundel	MD	306.6	71.4	8,342	4.5%
24005	Baltimore	Baltimore	MD	936.5	45.1	11,487	8.5%
24013	Baltimore	Carroll	MD	145.4	1.5	2,579	5.7%
24025	Baltimore	Harford	MD	251.7	42.9	3,608	8.2%
24027	Baltimore	Howard	MD	366.4	10.6	3,859	9.8%
24510	Baltimore	Baltimore	MD	1,186.5	1,357.0	15,594	16.3%
1073	Birmingham	Jefferson	AL	4,173.3	221.1	12,112	36.3%
1117	Birmingham	Shelby	AL	1,026.2	12.5	2,492	41.7%
1127	Birmingham	Walker	AL	649.1	97.7	1,530	48.8%
9007	Boston	Middlesex	CT	110.6	121.2	233	99.6%
25001	Boston	Barnstable	MA	232.2	490.2	4,681	15.4%
25005	Boston	Bristol	MA	436.1	214.3	7,364	8.8%
25007	Boston	Dukes	MA	0.0	1,332.0	1,732	76.9%
25009	Boston	Essex	MA	567.6	201.2	9,768	7.9%
25019	Boston	Nantucket	MA	0.0	256.8	530	48.4%
25021	Boston	Norfolk	MA	682.9	140.1	10,197	8.1%
25023	Boston	Plymouth	MA	363.1	191.5	6,163	9.0%
25025	Boston	Suffolk	MA	362.6	703.7	17,700	6.0%
25027	Boston	Worcester	MA	1,382.7	43.9	12,067	11.8%
33011	Boston	Hillsborough	NH	35.8	18.0	6,327	0.8%
33015	Boston	Rockingham	NH	27.0	928.5	6,652	14.4%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
47065	Chattanooga	Hamilton	TN	1,326.0	749.8	5,500	37.7%
47115	Chattanooga	Marion	TN	185.9	148.4	1,048	31.9%
47153	Chattanooga	Sequatchie	TN	0.0	0.0	73	0.0%
13047	Chattanooga	Catoosa	GA	402.1	0.3	953	42.2%
13083	Chattanooga	Dade	GA	382.0	0.0	814	46.9%
13295	Chattanooga	Walker	GA	0.0	0.3	555	0.1%
17031	Chicago	Cook	IL	18,683.3	5,549.0	69,728	34.8%
17043	Chicago	DuPage	IL	4,853.4	5.9	11,856	41.0%
17063	Chicago	Grundy	IL	436.8	161.9	1,367	43.8%
17089	Chicago	Kane	IL	1,791.2	4.2	3,786	47.4%
17093	Chicago	Kendall	IL	253.3	0.3	774	32.7%
17097	Chicago	Lake	IL	930.4	886.7	6,916	26.3%
17111	Chicago	McHenry	IL	496.6	7.0	1,870	26.9%
17197	Chicago	Will	IL	4,767.5	122.8	7,685	63.6%
18089	Chicago	Lake	IN	4,582.7	527.6	12,632	40.5%
18127	Chicago	Porter	IN	1,239.8	449.0	4,478	37.7%
18029	Cincinnati	Dearborn	IN	172.0	565.9	1,708	43.2%
21015	Cincinnati	Boone	KY	276.6	850.5	3,457	32.6%
21037	Cincinnati	Campbell	KY	522.3	588.4	2,204	50.4%
21117	Cincinnati	Kenton	KY	1,011.3	293.3	2,771	47.1%
39017	Cincinnati	Butler	OH	1,225.0	2.0	3,504	35.0%
39025	Cincinnati	Clermont	OH	53.0	1,117.4	3,185	36.7%
39061	Cincinnati	Hamilton	OH	1,208.2	3,308.4	13,388	33.7%
39165	Cincinnati	Warren	OH	188.0	3.8	1,673	11.5%
39007	Cleveland	Ashtabula	OH	833.8	4,487.1	9,441	56.4%
39035	Cleveland	Cuyahoga	OH	2,405.6	3,286.2	18,923	30.1%
39085	Cleveland	Lake	OH	568.9	773.0	3,859	34.8%
39093	Cleveland	Lorain	OH	1,360.5	2,917.8	8,463	50.5%
39103	Cleveland	Medina	OH	438.3	2.5	1,945	22.7%
39133	Cleveland	Portage	OH	851.4	10.3	2,483	34.7%
39153	Cleveland	Summit	OH	702.5	7.2	4,985	14.2%
26093	Detroit	Livingston	MI	80.7	2.3	2,010	4.1%
26099	Detroit	Macomb	MI	125.2	151.8	7,234	3.8%
26115	Detroit	Monroe	MI	591.7	231.4	2,799	29.4%
26125	Detroit	Oakland	MI	492.0	117.6	12,011	5.1%
26147	Detroit	St. Clair	MI	238.4	552.6	4,414	17.9%
26161	Detroit	Washtenaw	MI	137.0	1.6	3,811	3.6%
26163	Detroit	Wayne	MI	1,064.0	284.1	23,915	5.6%
48039	Houston	Brazoria	TX	615.5	6,160.6	12,492	54.2%
48071	Houston	Chambers	TX	35.1	208.0	1,047	23.2%
48157	Houston	Fort Bend	TX	855.7	4.0	4,021	21.4%
48167	Houston	Galveston	TX	481.5	14,101.9	24,831	58.7%
48201	Houston	Harris	TX	2,463.1	36,663.4	88,044	44.4%
48291	Houston	Liberty	TX	940.8	77.6	1,866	54.6%
48339	Houston	Montgomery	TX	732.9	11.6	4,332	17.2%
48473	Houston	Waller	TX	213.4	1.8	593	36.3%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
21019	Huntington	Boyd	KY	361.2	454.4	1,599	51.0%
21127	Huntington	Lawrence	KY	310.3	147.8	706	64.9%
39001	Huntington	Adams	OH	10.6	1,305.9	2,379	55.3%
39053	Huntington	Gallia	OH	93.0	574.4	1,310	50.9%
39087	Huntington	Lawrence	OH	337.7	852.5	2,252	52.8%
39145	Huntington	Scioto	OH	755.3	826.2	2,737	57.8%
54011	Huntington	Cabell	WV	789.0	630.5	10,401	13.6%
54053	Huntington	Mason	WV	175.0	993.3	2,088	56.0%
54099	Huntington	Wayne	WV	997.3	1,498.1	3,047	81.9%
18011	Indianapolis	Boone	IN	178.0	2.5	1,171	15.4%
18057	Indianapolis	Hamilton	IN	6.4	27.1	2,259	1.5%
18059	Indianapolis	Hancock	IN	138.0	1.4	1,042	13.4%
18063	Indianapolis	Hendricks	IN	490.3	1.4	1,989	24.7%
18081	Indianapolis	Johnson	IN	37.1	9.1	1,445	3.2%
18095	Indianapolis	Madison	IN	444.2	5.2	2,073	21.7%
18097	Indianapolis	Marion	IN	851.8	58.0	11,238	8.1%
18109	Indianapolis	Morgan	IN	16.9	9.6	1,015	2.6%
18145	Indianapolis	Shelby	IN	197.5	1.0	1,011	19.6%
20091	Kansas City	Johnson	KS	1,821.4	1.7	6,851	26.6%
20103	Kansas City	Leavenworth	KS	467.1	13.3	1,177	40.8%
20121	Kansas City	Miami	KS	2,667.9	6.6	3,085	86.7%
20209	Kansas City	Wyandotte	KS	985.3	111.7	2,919	37.6%
29037	Kansas City	Cass	MO	543.2	5.2	1,476	37.1%
29047	Kansas City	Clay	MO	984.8	118.0	3,214	34.3%
29049	Kansas City	Clinton	MO	0.0	7.0	435	1.6%
29095	Kansas City	Jackson	MO	3,099.6	837.4	12,014	32.8%
29107	Kansas City	Lafayette	MO	760.4	109.5	1,724	50.5%
29165	Kansas City	Platte	MO	741.9	25.2	2,964	25.9%
29177	Kansas City	Ray	MO	1,528.5	101.4	2,106	77.4%
6037	Los Angeles	Los Angeles	CA	8,078.6	34,699.8	126,737	33.8%
6059	Los Angeles	Orange	CA	2,064.2	1,935.3	27,820	14.4%
6065	Los Angeles	Riverside	CA	3,206.9	67.6	18,781	17.4%
6071	Los Angeles	San Bernardino	CA	10,808.1	31.6	26,747	40.5%
6111	Los Angeles	Ventura	CA	380.6	3,334.9	9,593	38.7%
27003	Minneapolis	Anoka	MN	688.9	350.5	4,088	25.4%
27019	Minneapolis	Carver	MN	1.7	29.2	848	3.6%
27037	Minneapolis	Dakota	MN	412.2	322.9	4,372	16.8%
27053	Minneapolis	Hennepin	MN	1,034.8	960.2	16,513	12.1%
27123	Minneapolis	Ramsey	MN	390.6	306.8	6,337	11.0%
27139	Minneapolis	Scott	MN	88.3	47.8	1,053	12.9%
27163	Minneapolis	Washington	MN	752.2	1,287.7	4,813	42.4%
9001	New York	Fairfield	CT	497.8	269.3	13,775	5.6%
9005	New York	Litchfield	CT	112.5	37.9	2,050	7.3%
34003	New York	Bergen	NJ	778.5	164.7	11,244	8.4%
34013	New York	Essex	NJ	153.0	43.8	11,579	1.7%

FIPS	MSA	County	ST	2020 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
34017	New York	Hudson	NJ	620.9	1,217.1	8,314	22.1%
34019	New York	Hunterdon	NJ	218.2	14.0	2,859	8.1%
34023	New York	Middlesex	NJ	393.0	235.8	9,099	6.9%
34025	New York	Monmouth	NJ	216.0	617.7	8,620	9.7%
34027	New York	Morris	NJ	149.1	22.5	6,081	2.8%
34029	New York	Ocean	NJ	13.6	500.0	6,071	8.5%
34031	New York	Passaic	NJ	139.0	21.8	5,226	3.1%
34035	New York	Somerset	NJ	368.6	0.7	3,670	10.1%
34037	New York	Sussex	NJ	40.5	26.7	1,901	3.5%
34039	New York	Union	NJ	278.8	880.2	7,151	16.2%
36005	New York	Bronx	NY	4.3	170.4	8,855	2.0%
36047	New York	Kings	NY	0.0	1,397.7	18,231	7.7%
36059	New York	Nassau	NY	0.0	506.2	11,407	4.4%
36061	New York	New York	NY	0.0	980.8	31,145	3.1%
36071	New York	Orange	NY	270.9	70.5	6,487	5.3%
36081	New York	Queens	NY	2.0	1,679.8	22,109	7.6%
36085	New York	Richmond	NY	0.0	1,942.3	4,992	38.9%
36087	New York	Rockland	NY	219.1	19.6	2,500	9.6%
36103	New York	Suffolk	NY	0.0	1,342.6	14,755	9.1%
36119	New York	Westchester	NY	0.0	117.2	7,870	1.5%
10003	Philadelphia	New Castle	DE	803.4	2,069.6	11,598	24.8%
24015	Philadelphia	Cecil	MD	213.9	56.2	2,142	12.6%
24029	Philadelphia	Kent	MD	1.8	53.8	541	10.3%
24031	Philadelphia	Montgomery	MD	627.6	15.6	12,024	5.3%
34005	Philadelphia	Burlington	NJ	0.0	963.9	6,299	15.3%
34007	Philadelphia	Camden	NJ	111.6	385.6	7,049	7.1%
34011	Philadelphia	Cumberland	NJ	23.4	1,063.5	3,128	34.8%
34015	Philadelphia	Gloucester	NJ	38.0	520.5	6,743	8.3%
34021	Philadelphia	Mercer	NJ	133.5	119.1	5,604	4.5%
34033	Philadelphia	Salem	NJ	9.3	315.8	1,442	22.5%
42017	Philadelphia	Bucks	PA	65.3	40.8	6,119	1.7%
42029	Philadelphia	Chester	PA	304.0	6.8	5,242	5.9%
42045	Philadelphia	Delaware	PA	125.2	4,798.6	12,519	39.3%
42101	Philadelphia	Philadelphia	PA	215.5	8,420.9	28,921	29.9%
4013	Phoenix	Maricopa	AZ	3,043.5	33.6	36,074	8.5%
4021	Phoenix	Pinal	AZ	1,689.8	7.5	4,626	36.7%
6019	San Joaquin	Fresno	CA	596.5	38.7	9,566	6.6%
6029	San Joaquin	Kern	CA	2,751.1	14.4	11,518	24.0%
6031	San Joaquin	Kings	CA	72.7	1.4	1,747	4.2%
6039	San Joaquin	Madera	CA	652.3	10.6	2,530	26.2%
6047	San Joaquin	Merced	CA	574.3	30.5	3,697	16.4%
6077	San Joaquin	San Joaquin	CA	980.7	496.4	7,856	18.8%
6099	San Joaquin	Stanislaus	CA	401.8	14.8	4,881	8.5%
6107	San Joaquin	Tulare	CA	905.5	10.6	5,493	16.7%
53029	Seattle	Island	WA	0.0	1,709.1	2,406	71.1%
53033	Seattle	King	WA	935.0	4,874.1	26,130	22.2%

FIPS	MSA	County	ST	2020 NOx Diesel Locomotive	2020 NOx Diesel Marine	2020 NOx Total Mobile	2020 NOx LM Percent
53035	Seattle	Kitsap	WA	0.0	54.6	2,268	2.4%
53045	Seattle	Mason	WA	0.1	28.7	541	5.3%
53053	Seattle	Pierce	WA	586.2	4,359.7	12,505	39.6%
53061	Seattle	Snohomish	WA	1,050.1	779.7	7,046	26.0%
53067	Seattle	Thurston	WA	267.7	317.1	3,088	18.9%
17027	St. Louis	Clinton	IL	653.3	3.4	1,223	53.7%
17083	St. Louis	Jersey	IL	54.0	473.6	1,104	47.8%
17119	St. Louis	Madison	IL	321.8	257.9	3,094	18.7%
17133	St. Louis	Monroe	IL	1,017.1	415.5	2,060	69.5%
17163	St. Louis	St. Clair	IL	339.2	491.8	3,360	24.7%
29055	St. Louis	Crawford	MO	149.4	1.7	640	23.6%
29071	St. Louis	Franklin	MO	1,005.6	63.6	2,226	48.0%
29099	St. Louis	Jefferson	MO	273.6	424.7	2,736	25.5%
29113	St. Louis	Lincoln	MO	451.5	172.5	1,301	48.0%
29183	St. Louis	St. Charles	MO	543.8	393.2	3,393	27.6%
29189	St. Louis	St. Louis	MO	867.4	489.5	12,921	10.5%
29219	St. Louis	Warren	MO	92.1	61.3	595	25.8%
29510	St. Louis	St. Louis	MO	874.5	6,486.7	13,766	53.5%

Table 0-111 2030 Locomotive and Diesel Marine NOx Tons/Year and Percent of Total Mobile Sources

FIPS	MSA	County	ST	2030 NOx Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
13013	Atlanta	Barrow	GA	186.5	0.7	583	32.1%
13015	Atlanta	Bartow	GA	665.4	9.2	1,596	42.3%
13045	Atlanta	Carroll	GA	180.2	3.9	1,168	15.8%
13057	Atlanta	Cherokee	GA	0.0	8.8	1,502	0.6%
13063	Atlanta	Clayton	GA	350.2	1.3	2,912	12.1%
13067	Atlanta	Cobb	GA	918.9	3.6	5,714	16.1%
13077	Atlanta	Coweta	GA	462.3	2.6	1,676	27.7%
13089	Atlanta	DeKalb	GA	426.2	2.3	5,791	7.4%
13097	Atlanta	Douglas	GA	165.0	0.7	1,146	14.5%
13113	Atlanta	Fayette	GA	119.7	1.6	1,109	10.9%
13117	Atlanta	Forsyth	GA	0.0	18.3	1,115	1.6%
13121	Atlanta	Fulton	GA	1,251.8	4.9	13,644	9.2%
13135	Atlanta	Gwinnett	GA	318.0	3.3	4,804	6.7%
13139	Atlanta	Hall	GA	185.4	30.1	1,581	13.6%
13149	Atlanta	Heard	GA	0.0	4.3	100	4.3%
13151	Atlanta	Henry	GA	472.0	1.6	1,860	25.5%
13217	Atlanta	Newton	GA	53.5	2.3	800	7.0%
13223	Atlanta	Paulding	GA	391.3	1.3	1,152	34.1%
13237	Atlanta	Putnam	GA	10.3	13.8	169	14.2%
13247	Atlanta	Rockdale	GA	75.8	1.3	848	9.1%
13255	Atlanta	Spalding	GA	20.4	1.3	597	3.6%
13297	Atlanta	Walton	GA	64.1	0.7	550	11.8%
24003	Baltimore	Anne Arundel	MD	285.6	76.7	8,572	4.2%
24005	Baltimore	Baltimore	MD	896.2	48.2	11,329	8.3%
24013	Baltimore	Carroll	MD	145.3	1.7	2,442	6.0%
24025	Baltimore	Harford	MD	242.3	45.7	3,508	8.2%
24027	Baltimore	Howard	MD	347.0	10.7	3,770	9.5%
24510	Baltimore	Baltimore	MD	1,142.1	1,365.5	17,705	14.2%
1073	Birmingham	Jefferson	AL	4,081.7	223.2	10,639	40.5%
1117	Birmingham	Shelby	AL	1,005.0	13.6	2,211	46.1%
1127	Birmingham	Walker	AL	648.6	99.0	1,403	53.3%
9007	Boston	Middlesex	CT	105.1	127.5	234	99.4%
25001	Boston	Barnstable	MA	232.0	518.9	4,797	15.7%
25005	Boston	Bristol	MA	435.3	220.7	7,523	8.7%
25007	Boston	Dukes	MA	0.0	1,350.2	1,773	76.2%
25009	Boston	Essex	MA	567.2	212.4	9,820	7.9%
25019	Boston	Nantucket	MA	0.0	265.1	551	48.1%
25021	Boston	Norfolk	MA	679.2	142.8	10,138	8.1%
25023	Boston	Plymouth	MA	362.5	205.8	6,197	9.2%
25025	Boston	Suffolk	MA	360.0	710.3	16,310	6.6%
25027	Boston	Worcester	MA	1,368.9	47.6	11,980	11.8%
33011	Boston	Hillsborough	NH	35.8	19.5	6,461	0.9%
33015	Boston	Rockingham	NH	27.0	940.3	6,892	14.0%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
47065	Chattanooga	Hamilton	TN	1,305.7	757.2	5,151	40.1%
47115	Chattanooga	Marion	TN	183.1	150.6	932	35.8%
47153	Chattanooga	Sequatchie	TN	0.0	0.0	56	0.0%
13047	Chattanooga	Catoosa	GA	395.9	0.3	830	47.8%
13083	Chattanooga	Dade	GA	376.2	0.0	699	53.8%
13295	Chattanooga	Walker	GA	0.0	0.3	438	0.1%
17031	Chicago	Cook	IL	18,514.9	5,645.1	63,116	38.3%
17043	Chicago	DuPage	IL	4,720.6	6.5	10,269	46.0%
17063	Chicago	Grundy	IL	427.7	163.2	1,168	50.6%
17089	Chicago	Kane	IL	1,750.8	4.6	3,281	53.5%
17093	Chicago	Kendall	IL	250.2	0.4	641	39.1%
17097	Chicago	Lake	IL	906.2	955.2	6,310	29.5%
17111	Chicago	McHenry	IL	488.4	7.6	1,548	32.0%
17197	Chicago	Will	IL	4,733.7	124.5	7,002	69.4%
18089	Chicago	Lake	IN	4,451.2	562.4	12,715	39.4%
18127	Chicago	Porter	IN	1,230.3	477.1	4,520	37.8%
18029	Cincinnati	Dearborn	IN	171.1	569.5	1,694	43.7%
21015	Cincinnati	Boone	KY	272.4	856.3	3,615	31.2%
21037	Cincinnati	Campbell	KY	514.0	592.5	2,128	52.0%
21117	Cincinnati	Kenton	KY	995.8	295.2	2,456	52.6%
39017	Cincinnati	Butler	OH	1,215.2	2.2	2,901	42.0%
39025	Cincinnati	Clermont	OH	52.6	1,124.0	3,076	38.2%
39061	Cincinnati	Hamilton	OH	1,200.0	3,327.7	12,598	35.9%
39165	Cincinnati	Warren	OH	187.1	4.2	1,261	15.2%
39007	Cleveland	Ashtabula	OH	826.5	4,523.2	10,335	51.8%
39035	Cleveland	Cuyahoga	OH	2,374.0	3,348.9	17,334	33.0%
39085	Cleveland	Lake	OH	563.9	800.5	3,676	37.1%
39093	Cleveland	Lorain	OH	1,350.4	2,952.3	8,584	50.1%
39103	Cleveland	Medina	OH	435.4	2.7	1,508	29.1%
39133	Cleveland	Portage	OH	844.5	11.2	2,012	42.5%
39153	Cleveland	Summit	OH	696.4	7.8	3,944	17.9%
26093	Detroit	Livingston	MI	79.5	2.5	1,589	5.2%
26099	Detroit	Macomb	MI	123.3	156.2	6,116	4.6%
26115	Detroit	Monroe	MI	582.6	234.6	2,409	33.9%
26125	Detroit	Oakland	MI	484.2	119.1	10,112	6.0%
26147	Detroit	St. Clair	MI	234.3	559.6	4,539	17.5%
26161	Detroit	Washtenaw	MI	135.7	1.7	3,199	4.3%
26163	Detroit	Wayne	MI	1,061.8	292.0	21,886	6.2%
48039	Houston	Brazoria	TX	606.1	6,200.9	13,541	50.3%
48071	Houston	Chambers	TX	34.6	213.6	964	25.8%
48157	Houston	Fort Bend	TX	841.8	4.3	3,437	24.6%
48167	Houston	Galveston	TX	483.0	14,191.0	27,937	52.5%
48201	Houston	Harris	TX	2,459.9	36,874.9	91,005	43.2%
48291	Houston	Liberty	TX	926.1	78.5	1,679	59.8%
48339	Houston	Montgomery	TX	721.7	12.6	3,561	20.6%
48473	Houston	Waller	TX	210.1	1.9	497	42.7%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
21019	Huntington	Boyd	KY	355.3	457.1	1,606	50.6%
21127	Huntington	Lawrence	KY	310.0	148.8	704	65.2%
39001	Huntington	Adams	OH	10.5	1,313.4	2,628	50.4%
39053	Huntington	Gallia	OH	92.3	577.8	1,377	48.7%
39087	Huntington	Lawrence	OH	335.2	857.5	2,351	50.7%
39145	Huntington	Scioto	OH	749.9	831.1	2,788	56.7%
54011	Huntington	Cabell	WV	775.3	634.9	13,900	10.1%
54053	Huntington	Mason	WV	174.8	1,000.4	2,292	51.3%
54099	Huntington	Wayne	WV	981.9	1,507.4	3,047	81.7%
18011	Indianapolis	Boone	IN	175.6	2.7	922	19.3%
18057	Indianapolis	Hamilton	IN	6.6	29.4	1,804	2.0%
18059	Indianapolis	Hancock	IN	136.6	1.6	816	16.9%
18063	Indianapolis	Hendricks	IN	486.8	1.6	1,616	30.2%
18081	Indianapolis	Johnson	IN	37.8	9.9	1,158	4.1%
18095	Indianapolis	Madison	IN	440.3	5.6	1,721	25.9%
18097	Indianapolis	Marion	IN	845.5	62.9	9,848	9.2%
18109	Indianapolis	Morgan	IN	17.2	10.4	785	3.5%
18145	Indianapolis	Shelby	IN	195.8	1.1	797	24.7%
20091	Kansas City	Johnson	KS	1,793.4	1.8	5,960	30.1%
20103	Kansas City	Leavenworth	KS	460.0	13.6	1,012	46.8%
20121	Kansas City	Miami	KS	2,627.2	7.1	2,928	90.0%
20209	Kansas City	Wyandotte	KS	969.7	112.5	2,648	40.9%
29037	Kansas City	Cass	MO	534.4	5.7	1,248	43.3%
29047	Kansas City	Clay	MO	980.2	120.2	2,864	38.4%
29049	Kansas City	Clinton	MO	0.0	7.6	320	2.4%
29095	Kansas City	Jackson	MO	3,078.5	843.5	10,916	35.9%
29107	Kansas City	Lafayette	MO	748.8	111.3	1,515	56.8%
29165	Kansas City	Platte	MO	730.6	26.2	2,855	26.5%
29177	Kansas City	Ray	MO	1,515.9	102.4	1,995	81.1%
6037	Los Angeles	Los Angeles	CA	8,037.8	34,907.8	110,332	38.9%
6059	Los Angeles	Orange	CA	2,064.0	1,951.1	22,503	17.8%
6065	Los Angeles	Riverside	CA	3,176.5	73.4	12,138	26.8%
6071	Los Angeles	San Bernardino	CA	10,729.1	34.3	20,287	53.1%
6111	Los Angeles	Ventura	CA	379.6	3,359.2	8,627	43.3%
27003	Minneapolis	Anoka	MN	677.4	359.0	3,678	28.2%
27019	Minneapolis	Carver	MN	1.7	31.1	683	4.8%
27037	Minneapolis	Dakota	MN	405.5	330.0	3,860	19.1%
27053	Minneapolis	Hennepin	MN	1,018.8	979.0	15,108	13.2%
27123	Minneapolis	Ramsey	MN	384.3	313.5	5,585	12.5%
27139	Minneapolis	Scott	MN	86.9	50.7	871	15.8%
27163	Minneapolis	Washington	MN	740.1	1,300.7	4,730	43.1%
9001	New York	Fairfield	CT	484.0	285.7	13,975	5.5%
9005	New York	Litchfield	CT	114.5	41.2	2,010	7.7%
34003	New York	Bergen	NJ	756.3	167.5	11,281	8.2%
34013	New York	Essex	NJ	146.0	44.6	13,693	1.4%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
34017	New York	Hudson	NJ	596.4	1,227.0	11,022	16.5%
34019	New York	Hunterdon	NJ	210.5	15.2	2,703	8.4%
34023	New York	Middlesex	NJ	377.1	238.9	10,943	5.6%
34025	New York	Monmouth	NJ	196.7	637.0	8,926	9.3%
34027	New York	Morris	NJ	138.6	24.4	5,958	2.7%
34029	New York	Ocean	NJ	12.6	539.0	6,186	8.9%
34031	New York	Passaic	NJ	129.1	23.6	5,198	2.9%
34035	New York	Somerset	NJ	358.4	0.8	3,620	9.9%
34037	New York	Sussex	NJ	41.2	29.0	1,794	3.9%
34039	New York	Union	NJ	265.7	885.6	8,205	14.0%
36005	New York	Bronx	NY	4.3	172.6	9,872	1.8%
36047	New York	Kings	NY	0.0	1,407.8	23,002	6.1%
36059	New York	Nassau	NY	0.0	516.6	11,386	4.5%
36061	New York	New York	NY	0.0	987.0	17,781	5.6%
36071	New York	Orange	NY	263.2	72.3	6,601	5.1%
36081	New York	Queens	NY	1.9	1,692.5	24,125	7.0%
36085	New York	Richmond	NY	0.0	1,955.3	6,930	28.2%
36087	New York	Rockland	NY	215.1	21.3	2,459	9.6%
36103	New York	Suffolk	NY	0.0	1,408.8	14,851	9.5%
36119	New York	Westchester	NY	0.0	121.2	8,399	1.4%
10003	Philadelphia	New Castle	DE	781.2	2,083.0	12,157	23.6%
24015	Philadelphia	Cecil	MD	210.9	59.2	2,059	13.1%
24029	Philadelphia	Kent	MD	1.8	57.6	506	11.7%
24031	Philadelphia	Montgomery	MD	593.4	16.1	12,274	5.0%
34005	Philadelphia	Burlington	NJ	0.0	971.5	6,198	15.7%
34007	Philadelphia	Camden	NJ	104.7	388.6	7,322	6.7%
34011	Philadelphia	Cumberland	NJ	23.8	1,083.2	3,125	35.4%
34015	Philadelphia	Gloucester	NJ	36.9	525.2	7,922	7.1%
34021	Philadelphia	Mercer	NJ	131.1	120.3	5,616	4.5%
34033	Philadelphia	Salem	NJ	9.4	320.5	1,393	23.7%
42017	Philadelphia	Bucks	PA	63.2	43.1	6,003	1.8%
42029	Philadelphia	Chester	PA	290.2	7.4	5,004	5.9%
42045	Philadelphia	Delaware	PA	120.5	4,827.0	13,735	36.0%
42101	Philadelphia	Philadelphia	PA	213.8	8,470.2	31,412	27.6%
4013	Phoenix	Maricopa	AZ	3,019.1	36.5	18,989	16.1%
4021	Phoenix	Pinal	AZ	1,660.1	8.1	4,001	41.7%
6019	San Joaquin	Fresno	CA	590.6	42.0	5,860	10.8%
6029	San Joaquin	Kern	CA	2,741.2	15.7	7,256	38.0%
6031	San Joaquin	Kings	CA	71.7	1.5	902	8.1%
6039	San Joaquin	Madera	CA	644.9	11.5	1,488	44.1%
6047	San Joaquin	Merced	CA	573.0	33.1	2,108	28.7%
6077	San Joaquin	San Joaquin	CA	974.8	501.1	5,322	27.7%
6099	San Joaquin	Stanislaus	CA	398.9	16.0	2,978	13.9%
6107	San Joaquin	Tulare	CA	898.7	11.5	3,414	26.7%
53029	Seattle	Island	WA	0.0	1,720.9	2,318	74.2%
53033	Seattle	King	WA	919.1	4,923.0	23,930	24.4%

FIPS	MSA	County	ST	2030 NOx			
				Diesel Locomotive	Diesel Marine	Total Mobile	LM Percent
53035	Seattle	Kitsap	WA	0.0	59.2	1,921	3.1%
53045	Seattle	Mason	WA	0.1	30.6	449	6.8%
53053	Seattle	Pierce	WA	576.1	4,394.7	12,254	40.6%
53061	Seattle	Snohomish	WA	1,033.3	793.9	6,039	30.3%
53067	Seattle	Thurston	WA	266.9	322.4	2,775	21.2%
17027	St. Louis	Clinton	IL	645.5	3.7	1,056	61.4%
17083	St. Louis	Jersey	IL	53.2	476.4	1,134	46.7%
17119	St. Louis	Madison	IL	312.6	259.6	2,469	23.2%
17133	St. Louis	Monroe	IL	1,008.1	417.9	2,049	69.6%
17163	St. Louis	St. Clair	IL	328.1	494.8	2,832	29.1%
29055	St. Louis	Crawford	MO	149.3	1.9	526	28.7%
29071	St. Louis	Franklin	MO	988.2	64.9	1,850	56.9%
29099	St. Louis	Jefferson	MO	269.4	428.0	2,271	30.7%
29113	St. Louis	Lincoln	MO	444.6	174.7	1,179	52.5%
29183	St. Louis	St. Charles	MO	535.5	399.3	2,847	32.8%
29189	St. Louis	St. Louis	MO	853.1	494.2	11,003	12.2%
29219	St. Louis	Warren	MO	90.7	62.4	503	30.4%
29510	St. Louis	St. Louis	MO	880.1	6,524.3	14,654	50.5%

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LOCOMOTIVE AND MARINE TECHNOLOGICAL FEASIBILITY

CHAPTER 4: Locomotive and Marine Technological Feasibility

In this chapter we describe in detail the emissions control technologies we believe may be used to meet the standards we are proposing. Because of the range of engines and applications we cover in this proposal, our proposed standards span a range of emissions levels. Correspondingly, we have identified a number of different emissions control technologies we expect may be used to meet the proposed standards. These technologies range from incremental improvements to existing engine components to highly advanced catalytic exhaust treatment systems.

In this chapter we first summarize our current locomotive and marine diesel engine standards and provide an overview of existing and future emissions control technologies. We believe that further improvements in existing technologies may be used to meet the standards we are proposing for existing engines that are remanufactured as new (i.e., Tier 0, Tier 1, Tier 2). We then describe how technologies similar to some of those already being implemented to meet our current and upcoming heavy-duty highway and nonroad diesel engine emissions standards may be applied to meet our proposed interim standards for new engines (i.e., Tier 3). We conclude this section with a discussion of catalytic exhaust treatment technologies that we believe may be used to meet our proposed Tier 4 standards.

All of our analyses in this chapter include how we expect these technologies to perform throughout their useful life as well as how we believe they would be implemented specifically into locomotive and marine applications. Note that much of this chapter's content is based upon the performance of currently available emissions control technologies and results from testing that has already been completed. In most cases the already-published results show that currently available emissions control technologies can be implemented without further improvements to meet the standards we are proposing. In a few cases, we are projecting that further improvements to these technologies will be made between now and the Tier 4 standards implementation dates. These projected improvements will enable engine manufacturers to meet the standards we are proposing.

4.1 Overview of Emissions Standards and Emissions Control Technologies

Our current locomotive and marine diesel engine standards have already decreased NO_x emissions from unregulated levels. For example, since 1997, NO_x emissions standards for diesel locomotive engines have been reduced from an unregulated level of about 13.5 g/bhp-hr to the current Tier 2 level of 5.5 g/bhp-hr – a 60% reduction when evaluated over the locomotive line-haul duty cycle. Similar NO_x reductions have been realized for Category 1 & 2 (C1 & C2) commercial marine diesel engines. Our Tier 1 marine standards are equivalent to the International

Maritime Organization's NO_x regulation known as MARPOL Annex VI. Beginning in 2004, these standards became mandatory for C1 & C2 Commercial vessels, and were voluntary in prior years. Beginning in 2007, EPA Tier 2 standards for C1 & C2 Commercial vessels will supersede these MARPOL-equivalent standards. For a high-speed marine diesel engine, NO_x will be reduced from a Tier 1 level of 9.8 g/kW-hr to 7.5 g/kW-hr - a 23% reduction. While these reductions in locomotive and marine NO_x emissions are significant, they do not keep pace with the 90% NO_x reduction (from 2.0 g/bhp-hr to 0.2 g/bhp-hr) set forth in the 2007 Heavy-Duty Highway Rule.[1] Neither do these reductions keep pace with the approximately 85% NO_x reductions set forth in the Nonroad Tier 4 Standards for 56 kW to 560 kW engines and for generator sets above 560 kW[2,3]. In a similar manner, locomotive and marine particulate matter (PM) emission reductions also lag behind the Heavy-Duty Highway and Nonroad Tier 4 Rules. For line-haul and switcher locomotives, a 67% reduction in PM already has been achieved in going from the Tier 0 to the Tier 2 standards. On the marine side, PM emissions for C1 & C2 Commercial have been reduced from an unregulated level prior to May 2005, to a 0.2-0.4 g/kW-hr level for Tier 2.

[A] In contrast, the 2007 Heavy-Duty Highway Rule set forth PM reductions of 90% - from 0.1 g/bhp-hr to 0.01 g/bhp-hr. Similarly post-2014 Nonroad Tier 4 PM emissions will be reduced 85 to 95% compared to Tier 3 Nonroad PM emissions for 56 kW to 560 kW engines and for generator sets above 560 kW.[2,3] In the timeframe of the Tier 3 and 4 Locomotive Standards that we are proposing, NO_x and PM emissions will continue to be a serious threat to public health, and, on a percentage basis, the locomotive and marine contributions to the nationwide inventory of these pollutants would continue to increase relative to today's levels if current Tier 2 emission levels were maintained. Please refer to Chapter 3 of the Regulatory Impact Analysis for a more detailed discussion of the contribution of locomotive and marine emissions to the NO_x and PM inventory.

To date, the Tier 0 through Tier 2 locomotive and Tier 1 through Tier 2 marine emissions reductions have been achieved largely through engine calibration optimization and engine hardware design changes (e.g. improved fuel injectors, increased injection pressure, intake air after-cooling, combustion chamber design, injection timing, reduced oil consumption, etc.). To achieve the Tier 3 PM emission standards we are proposing, further reductions in lubricating oil consumption will be required. This will most likely be achieved via improvements to piston, piston ring, and cylinder liner design, as well as improvements to the crankcase ventilation system. To further reduce NO_x and PM emission beyond Tier 3 levels, an exhaust aftertreatment approach will be necessary.

[A] Tier 2 PM emission standards are dependent on an engine's volumetric displacement-per-cylinder.

Selective catalytic reduction (SCR) is a commonly-used aftertreatment device for meeting more stringent NO_x emissions standards in worldwide diesel applications. Stationary, coal-fired power plants have used SCR for three decades as a means of controlling NO_x emissions, and currently, European heavy-duty truck manufacturers are using this technology to meet the Euro IV and Euro V limits. To a lesser extent, SCR has been introduced on diesels in the U.S. market, but the applications have been limited to marine ferryboat and stationary power generation demonstration projects in California and several northeast states. However, by 2010, when 100% of the heavy-duty diesel trucks are required to meet the NO_x limits of the 2007 heavy-duty Highway Rule, several heavy-duty truck engine manufacturers have indicated that they will use SCR technology to meet these standards.[4,5] While other promising NO_x-reducing technologies such as lean NO_x catalysts, NO_x adsorbers, and advanced combustion control continue to be developed - and may be viable approaches to the standards we are proposing today - our analysis projects that SCR will be the technology chosen by the locomotive and marine diesel industries to meet the Tier 4 NO_x standards we are proposing. For a complete review of these other alternative NO_x emissions control technologies refer to the Regulatory Impact Analysis from our Clean Air Nonroad diesel rule.[6]

The most effective exhaust aftertreatment used for diesel PM emissions control is the diesel particulate filter (DPF). More than a million light diesel vehicles that are OEM-equipped with DPF systems have been sold in Europe, and over 200,000 DPF retrofits to diesel engines have been conducted worldwide.[7] Broad application of catalyzed diesel particulate filter (CDPF) systems with greater than 90% PM control is beginning with the introduction of 2007 model year heavy-duty diesel trucks in the United States. These systems use a combination of both passive and active soot regeneration. Our analysis projects that CDPF systems with a combination of passive and active backup regeneration will be the primary technology chosen by the locomotive and marine diesel industries to meet the Tier 4 PM standards we are proposing.

4.2 Emissions Control Technologies for Remanufactured Engine Standards and for Tier 3 New Engine Interim Standards

To meet our proposed locomotive remanufactured engine standards, our potential marine remanufactured engine standards, and our proposed Tier 3 locomotive and marine standards, we believe engine manufacturers will utilize incremental improvements to existing engine components to reduce engine-out emissions. This will be accomplished primarily via application of technology originally developed to meet our current and upcoming standards for heavy-duty on-highway trucks and nonroad diesel equipment. This is especially true for many of the Category 1 and Category 2 marine engines, which are based on nonroad engine designs. This will allow introduction of technology originally developed to meet nonroad Tier 3 and Tier 4 standards to be used to meet the Tier 3 marine standards. Table 4-1, Table 4-2 and Table 4-3 provide summaries of the technologies that we believe may be used meet the remanufactured engine and Tier 3 new engine interim standards for switch locomotives, line-haul locomotives and marine engines, respectively.

Table 4-1: Technologies for switch locomotive standards through Tier 3

Year	Standard	NO_x (g/bhp-hr)	PM (g/bhp-hr)	Technology added to engine
2010	T0-Remanufactured	11.8	0.26	New power assemblies to improve oil consumption, improved mechanical unit injectors
2010	T1-Remanufactured	11.0	0.26	New power assemblies to improve oil consumption, electronic unit injection, new unit injector cam profile
2013	T2-Remanufactured	8.1	0.13	For high-speed engines: Same as Tier 3 nonroad engines For medium-speed engines: Further improvements to power assembly and closed crankcase ventilation system to reduce oil consumption, new turbocharger, new engine calibration, new unit injector cam profile
2011	T3	5.0	0.10	For high-speed engines: Same as Tier 3 nonroad engines For medium-speed engines: Further improvements to power assembly and CCV to reduce oil consumption, high pressure common rail injection with post-injection PM clean-up, injection timing retard, new turbocharger

Table 4-2: Technologies for Line Haul Locomotive Standards up to Tier 3

Year	Standard	NO_x (g/bhp-hr)	PM (g/bhp-hr)	Technology added to engine
2010 (2008 if available)	T0-Remanufactured	7.4	0.22	New power assemblies to improve oil consumption, improved mechanical unit injectors or switch to electronic unit injection, new turbocharger
2010 (2008 if available)	T1-Remanufactured	7.4	0.22	New power assemblies to improve oil consumption, electronic unit injection, new unit injector cam profile, new turbocharger
2013	T2-Remanufactured	5.5	0.10	Further improvements to power assembly and CCV to reduce oil consumption, electronic unit injection or high pressure common rail injection
2012	T3	5.5	0.10	Further improvements to power assembly to reduce oil consumption, electronic unit injection or high pressure common rail injection

Table 4-3: Technologies for Marine Category 1 and Category 2 to meet Tier 3 Standards

Year	Standard	$HC+NO_x$ (g/bhp-hr)	PM (g/bhp-hr)	Technology added to engine
2009-2014	Category 1 Tier 3 Marine (< 75 kW)	3.5 – 5.6	0.22 – 0.33	Same engine-out NO_x technologies as Tier 4 nonroad—with no Tier 4 PM aftertreatment technologies
2012-2018	Category 1 Tier 3 Marine (75-3700 kW)	4.0 – 4.3	0.07 – 0.11	Recalibration on nonroad Tier 4 engines without aftertreatment
2013	Category 2 Tier 3 Marine 7 – 15 liters/cyl.	5.5	0.10	Same engine-out NO_x technologies as pre-2014, non-generator-set, Tier 4 nonroad—with no Tier 4 PM aftertreatment technologies
2012	Category 2 Tier 3 Marine 15 – 30 liters/cyl.	6.5 – 8.2	0.20	Further improvements to power assembly to reduce oil consumption, electronic unit injection or high pressure common rail injection, new turbocharger

In section 4.2.1.1 we will describe some of the fundamentals of diesel combustion and pollutant formation. In section 4.2.2 we describe the manner in which engine-out emissions can be controlled in order to meet the proposed locomotive remanufactured engine standards, potential marine remanufactured engine standards and the Tier 3 locomotive and marine standards.

4.2.1 Diesel Combustion and Pollutant Formation

In this section we describe the mechanisms of pollutant formation. In order to lay the foundation for this discussion, we begin with a review of diesel combustion, especially as it is related to 2-stroke cycle and 4-stroke cycle diesel engine operation. We describe both of these types of diesel engine operation because both 2-stroke and 4-stroke engines are used in locomotive and marine applications. We then describe NO_x, PM, HC, and CO formation mechanisms.

4.2.1.1 Diesel Combustion

Category 1 marine diesel engines operate on a four-stroke cycle. The larger displacement Category 2 marine diesel engines and locomotive diesel engines operate on either a two-stroke cycle or a four-stroke cycle. The four-stroke cycle consists of an intake stroke, a compression stroke, an expansion (also called the power or combustion) stroke, and an exhaust stroke. The two-stroke cycle combines the intake and exhaust functions by using forced cylinder scavenging. Figure 4-1 provides an overview and brief comparison of the two-stroke and four-stroke cycles used by marine and locomotive diesel engines.

The diesel combustion event provides the energy for piston work. An example of the relationship between the different phases of diesel combustion and the net energy released from the fuel is shown in Figure 4.2. Combustion starts near the end of compression and continues through a portion of the expansion stroke. Near the end of the piston compression stroke, fuel is injected into the cylinder at high pressure and mixes with the contents of the cylinder (air + any residual combustion gases). This period of premixing is referred to as ignition delay. Ignition delay ends when the premixed cylinder contents self-ignite due to the high temperature and pressure produced by the compression stroke in a relatively short, homogenous, premixed combustion event. Immediately following premixed combustion, diesel combustion becomes primarily non-homogeneous and diffusion-controlled. The rate of combustion is limited by the rate of fuel and oxygen mixing. During this phase of combustion, fuel injection continues creating a region that consists of fuel only. The fuel diffuses out of this region and air is entrained into this region creating an area where the fuel to air ratio is balanced (i.e., near stoichiometric conditions) to support combustion. The fuel burns primarily in this region. One way to visualize this is to roughly divide the cylinder contents into fuel-rich and fuel-lean sides of the reaction-zone where combustion is taking place as shown in Figure 4-3. As discussed in the following subsections, the pollutant rate of formation in a diesel engine is largely defined by these combustion regions and how they evolve during the combustion process.[8]

Figure 4-1: A comparison of 2 complete revolutions of the four-stroke (top) and two-stroke diesel combustion cycles. Note that the two-stroke cycle relies on intake air-flow to scavenge the exhaust products from the cylinder. In the case of uniflow scavenged two-stroke diesel engines, cylinder scavenging is assisted by the use of a centrifugal or positive displacement blower to pressurize the intake ports located on the sides of the cylinder. Exhaust exits the cylinder through cam-actuated poppet valves in the cylinder head. Four-stroke diesel engines are the predominant type of Category 1 marine engine. Both four-stroke and uniflow-scavenged two-stroke diesel engines are used for Category 2 marine and locomotive applications.

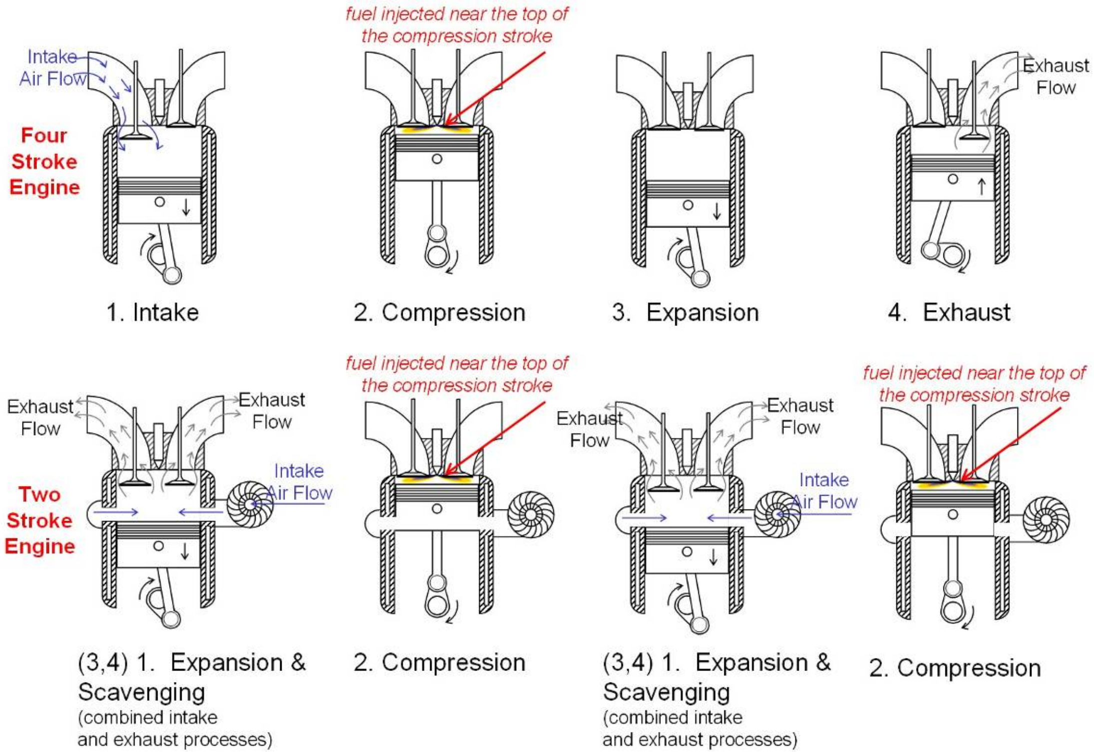


Figure 4-2: An idealized example of the net apparent rate of combustion heat release (derived from high-speed cylinder pressure measurements) for a direct injection diesel engine with indication of the major events and phases of combustion.

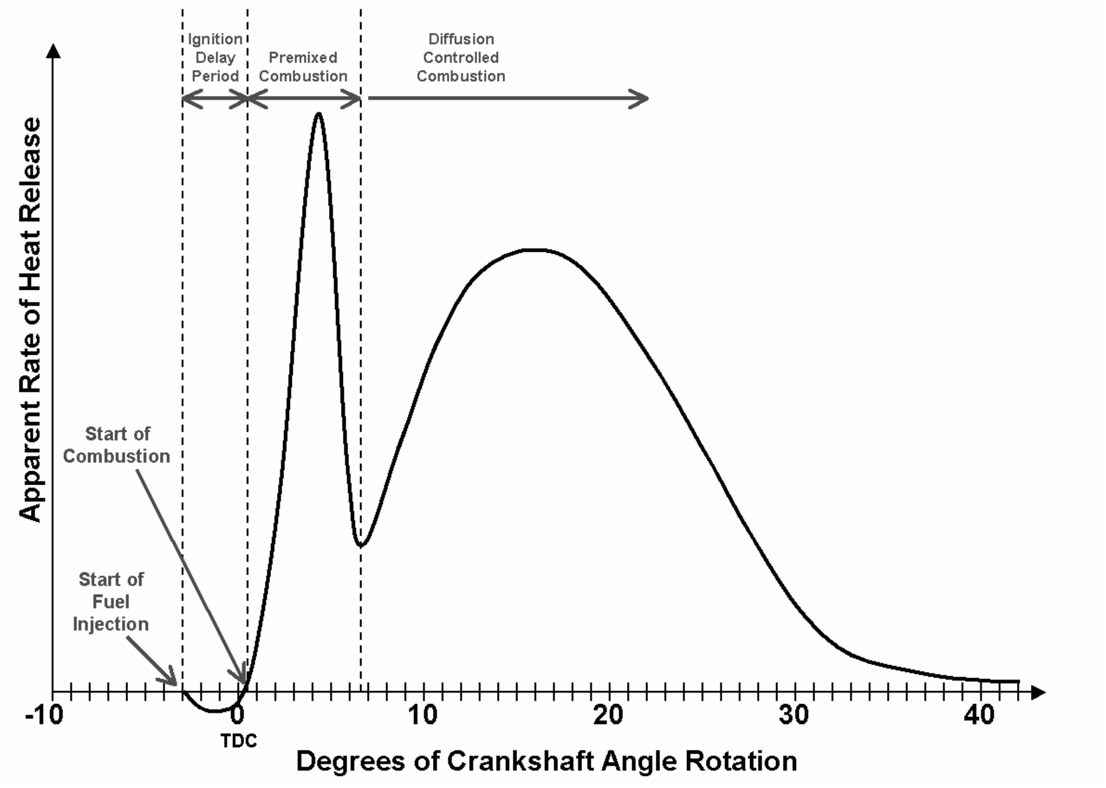
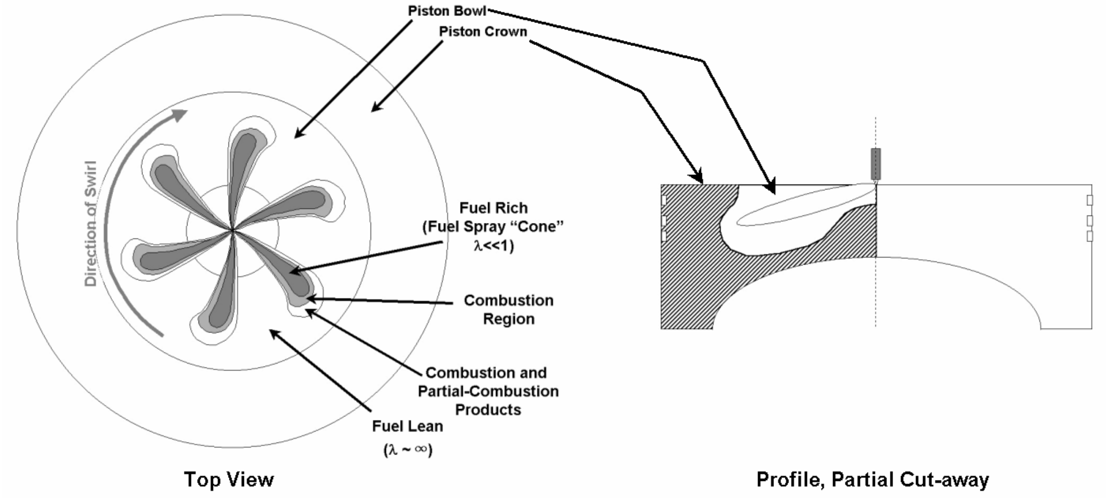


Figure 4-3: An idealized physical schematic of the diesel combustion process.



4.2.1.2 NO_x Emissions

Nitrogen oxides (NO_x) are formed in diesel engines by the oxidation of molecular nitrogen (N_2) in the stoichiometric combustion regions of the diffusion-controlled and premixed diesel combustion phases, described in the previous section. During the premixed phase of combustion, ignition and flame propagation occurs at high temperatures and at near stoichiometric mixtures of fuel and air. During diffusion-controlled combustion, the reaction zone is also near stoichiometric conditions. At the high temperatures present during premixed combustion or in the diffusion-controlled combustion reaction zone, a fraction of the nitrogen and oxygen can dissociate, forming radicals which then combine through a series of reactions to form nitric oxide (NO), the primary NO_x constituent. Nitrogen dioxide (NO_2), the other major NO_x constituent, is formed from oxidation of NO in the flame region. NO_2 formed during combustion rapidly decomposes to NO and molecular oxygen unless the reaction is quenched by mixing with cooler cylinder contents. Engine-out emissions of NO are typically 80% or more of total NO_x from direct injection diesel engines. The NO_x formation rate has a strong exponential relationship to temperature. Therefore, high temperatures result in high NO_x formation rates.[8,9] Any changes to engine design that can lower the peak temperature realized during combustion, the partial pressures of dissociated nitrogen and oxygen, or the duration of time at these peak temperatures can lower NO_x emissions. Most of the engine-out NO_x emission control technologies discussed in the following sections reduce NO_x emissions by reducing the peak combustion temperatures while balancing impacts on PM emissions, fuel consumption and torque output.

4.2.1.3 PM Emissions

Particulate matter (PM) emitted from diesel engines is a multi-component mixture composed chiefly of elemental carbon (or soot), semi-volatile organic carbon compounds, sulfate compounds (primarily sulfuric acid) with associated water, and trace quantities of metallic ash.

During diffusion-controlled combustion, fuel diffuses into a reaction zone and burns. Products of combustion and partial products of combustion diffuse away from the reaction zone where combustion occurs. At temperatures above 1300 K, fuel compounds on the fuel-rich side of the reaction zone can be pyrolized to form elemental carbon particles[10]. Most of the elemental carbon formed by fuel pyrolysis (80% to 98%) is oxidized during later stages of combustion.[11,12] The remaining elemental carbon agglomerates into complex chain-aggregate soot particles and leaves the engine as a component of PM emissions.

From this description, the formation of elemental carbon particles during combustion and emission as PM following the combustion event can be summarized as being dependent upon three primary factors:

1. Temperature
2. Residence time
3. Availability of oxidants

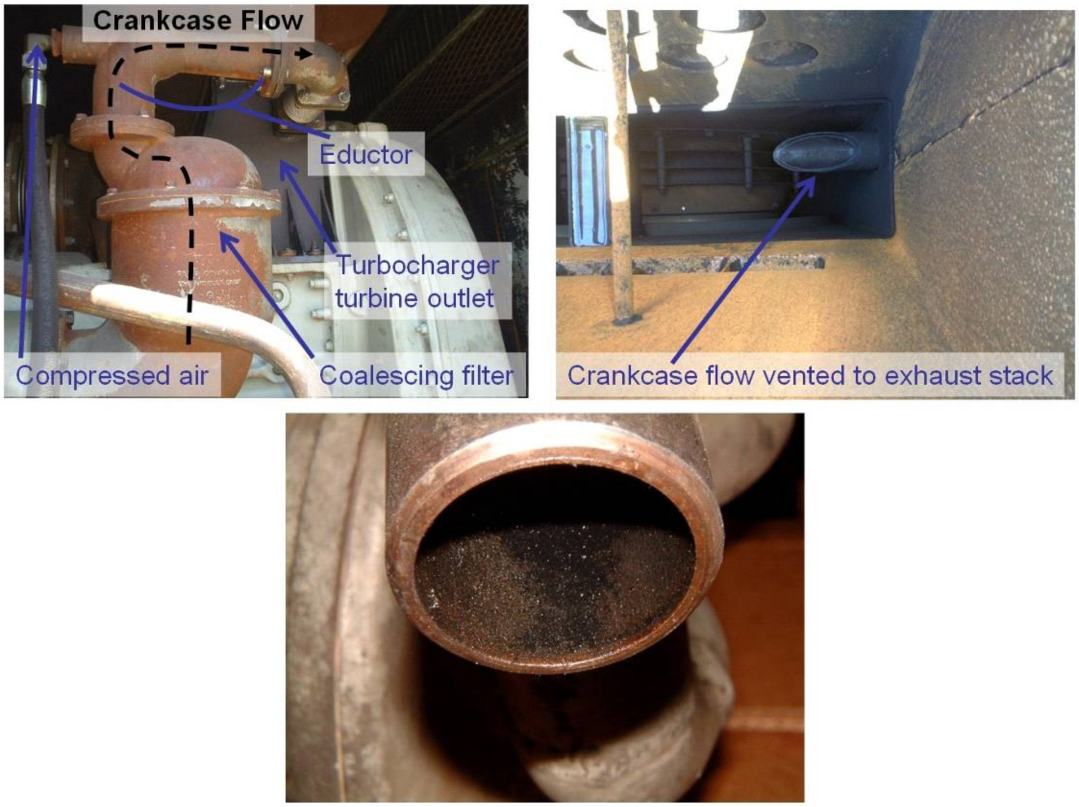
Thus, in-cylinder control of elemental carbon PM is accomplished by varying engine parameters that affect these variables while balancing the resultant effects on NO_x emissions and torque output.

The combinations of organic compounds (volatile and semi-volatile) that contribute to PM are referred to as the volatile organic fraction (VOF), the soluble organic fraction (SOF), or as organic carbon PM, depending upon the analytical procedure used to measure the compounds. Organic carbon PM primarily consists of lubricating oil and partial combustion products of lubricating oil. Some of the higher molecular weight fuel compounds from unburned or partially burned diesel fuel also contribute to organic carbon PM. Oil can be entrained into the cylinder contents from cylinder liner surfaces as they are uncovered by the piston and by leakage into the cylinder past the valve stems. Uniflow-scavenged two-stroke diesel engines typically have somewhat higher oil consumption and organic carbon PM emissions in part due to the lubricating oil entrained into the scavenging flow from around the intake ports in the cylinder wall. Compliance with the closed crankcase ventilation provisions in the Tier 0 and later locomotive and Tier 2 marine standards has typically been accomplished by using coarse filtration to separate a fraction of the oil aerosol from the crankcase flow and then entraining the crankcase flow directly into the exhaust downstream of the turbocharger exhaust turbine (Figure 4-4). Incomplete separation of the oil aerosol from the crankcase flow can increase the amount of lubricating oil directly entrained into the exhaust with subsequent formation of organic carbon PM.

Both organic carbon and sulfate PM are formed after cooling and air-dilution of the exhaust. Sulfur dioxide (SO_2) is formed via combustion of sulfur compounds from the fuel and lubricating oil burned during combustion. In the absence of post-combustion catalytic treatment of the exhaust, approximately 1 to 3 % of fuel sulfur is oxidized to ionic sulfate (SO_3^-) and upon further cooling is present primarily as a hydrated sulfuric acid aerosol. For example, sulfate PM currently accounts for approximately 0.03 to 0.04 g/bhp-hr over the line-haul cycle for locomotive engines using 3000 ppm sulfur nonroad diesel fuel.

Diesel oxidation catalysts (DOC) and catalyzed diesel particulate filters (CDPF) using platinum catalysts can oxidize the organic compounds thereby lowering PM emissions but they can also oxidize 50% or more of the SO_2 emissions to sulfate PM, depending on the exhaust temperature and the platinum content of the catalyst formulation that is used.

Figure 4-4: Crankcase ventilation system for a medium speed locomotive diesel engine. An eductor uses compressed air to draw crankcase gases through a coarse coalescing filter (top left photo). The outlet of the crankcase ventilation system can be clearly seen from the outlet of the locomotive's exhaust stack (top right photo). The bottom photo shows tubing from a crankcase ventilation system removed from downstream of a similar coarse coalescing filter. There was considerable wetting of the inner wall of the tubing with lubricating oil.



4.2.1.4 HC Emissions

Hydrocarbon (HC) emissions from diesel engines are generally much lower compared to other mobile sources due to engine operation that, on a bulk-cylinder-content basis, is significantly fuel-lean of the stoichiometric air-to-fuel ratio. HC emissions primarily occur due to fuel and lubricant trapped in crevices (e.g., at the top ring land and the injector sac) which prevents sufficient mixing with air for complete combustion. Fuel related HC can also be emitted due to "over mixing" during ignition delay, a condition where fuel in the induced swirl flow has mixed beyond the lean flammability limit. Higher molecular weight HC compounds adsorb to soot particles or nucleate and thus contribute to the organic carbon PM. Lower molecular weight HC compounds are primarily emitted in the gas phase. During engine start-up under cold ambient conditions or following prolonged engine idling, fuel-related HC can be emitted as a concentrated, condensed aerosol ("white smoke").

4.2.1.5 CO Emissions

Carbon monoxide emissions (CO) from diesel engines are generally low compared to other mobile sources due to engine operation that, on a bulk-cylinder-content basis, is significantly fuel-lean of the stoichiometric air-to-fuel ratio. Catalytic emission controls that effectively oxidize PM constituents and HC emissions are also effective for oxidation of CO, reducing CO emissions to even lower levels.

4.2.2 Engine-out Emissions Control

Control of diesel emissions via modification of combustion processes is often characterized by trade-offs in NO_x emissions control vs. other parameters such as PM emissions, fuel consumption, and lubricating oil soot loading. For example lower oxygen content (lowering the air-to-fuel ratio) lowers NO_x formation but increases PM formation. Advanced (earlier) injection timing reduces PM emissions but increases NO_x formation. Retarded (later) injection timing reduces NO_x formation but increases PM formation, increases fuel consumption, and at high torque output levels can increase soot accumulation within the lubricating oil. During engine development, these trade-offs are balanced against each other in order to obtain effective NO_x and PM control while maintaining acceptable power output, fuel efficiency and engine durability. The introduction of more-advanced fuel injection systems and improved turbocharging can improve these tradeoffs, allowing for reduced emisssions of both NO_x and PM.

4.2.2.1 Ultra Low Sulfur Diesel Fuel

We estimate that the use of ultra low sulfur diesel fuel (<15 ppm S) will reduce sulfate PM emissions from locomotive and marine engines by approximately 0.03 to 0.04 g/bhp-hr, as compared to PM emissions when ~3000 ppm S fuel is used. The use of ultra low sulfur fuel also reduces depletion of TBN in the oil and substantially reduces condensation of acidic aerosols within cooled exhaust gas recirculation systems (see section 4.2.2.5). In addition to the direct sulfate PM emissions reductions realized through the use of ULSD, ULSD is also necessary to enable the use of advanced aftertreatment technologies, as discussed later in this chapter. While we describe the emission reductions due to the use of lower sulfur diesel fuel here, we should be clear that these reductions are part of our baseline emissions inventory because this rule does not change the fuel sulfur standard.

4.2.2.2 Turbocharger Improvements

The majority of Category 1 and 2 marine diesel engines and Tier 0 and later locomotive diesel engines are equipped with turbocharging and aftercooling. Tier 0 and later two-stroke locomotive engines (and some Tier 1 and later marine engines) are equipped with a hybrid mechanical centrifugal supercharger/exhaust turbocharger system. This system is gear driven up to approximately the notch 6 operating mode and is exhaust driven at higher operating modes or higher numbered notches (e.g., notches 7 and 8). This arrangement helps to provide sufficient scavenging boost at lower notch settings where there is insufficient exhaust energy for the exhaust turbine to drive the compressor. Significant improvements have been made in recent years in matching turbocharger turbine and compressor performance to the highway, nonroad, marine, and locomotive diesel engines. Improvements to turbochargers and the match of the turbocharger's design to the engine reduce the incidence of insufficient oxygen during transients and help maintain sufficient air flow to the engine during high load operation. The corresponding improvements in oxygen availability throughout the operational range of the engine reduce the formation of elemental carbon PM. We expect that new Tier 0 and Tier 1 (remanufactured) locomotive engines will include improvements to turbocharger design that are similar to those of current Tier 2 locomotive designs. We also expect that engine manufacturers will continue with incremental improvements in turbochargers and the match of the turbocharger's design to Tier 3 locomotive and marine engines.

4.2.2.3 Charge Air Cooling

Improvements in engine-out NO_x emissions to meet our proposed locomotive remanufactured engine standards and the Tier 3 locomotive and marine standards will be accomplished in part via lowering charge air cooling temperature. This was one of the primary methods of used by locomotive engine manufacturers to reduce NO_x emissions to meet the Tier 1 and Tier 2 locomotive standards and the Tier 3 nonroad diesel standards. Lowering the intake manifold temperature lowers the peak temperature of combustion and thus NO_x emissions. The NO_x reduction realized from lowering the intake manifold temperature can vary depending upon the engine design but one estimate suggests NO_x emissions can be reduced by five to seven percent with every 10 °C decrease in intake manifold temperature.[13] Typically the intake manifold temperature is lowered by cooling the intake gases through a heat exchanger, also known as a charge air cooler or aftercooler, located between the turbocharger compressor outlet and the intake manifold. Locomotive applications typically use air-to-air aftercoolers. Locomotive aftercoolers use electrically powered auxiliary fans since oftentimes conditions at high torque output require significant intake air heat rejection, especially at speeds too low for effective passive air-flow. Operation of the locomotive in multi-engine train configurations or "consist" can also impede air-flow to heat exchangers. Increased cooling capacity in locomotive applications can be accomplished via increased air-flow through the air-to-air after cooler, often through use of either variable speed or multiple-staged electric fans. Marine applications with access to sea-water heat-exchanger coolant loops typically have excess heat rejection capacity with respect to charge air cooling. This cooling capacity can be limited within certain existing hull designs, but new hull designs can typically overcome these existing hull limitations.

4.2.2.4 Injection Timing

Electronic control of injection timing has been used by locomotive and marine engine manufacturers to balance NO_x emissions, PM emissions, fuel efficiency, engine performance and engine durability for engines certified to the Tier 2 locomotive and marine engine standards, Tier 3 nonroad standards, and the 1998 and later heavy-duty highway standards. We expect similar systems to be used to comply with our proposed remanufactured engine standards and will continue to be used to comply with our proposed Tier 3 locomotive and marine standards.

Delaying the start of fuel injection and thus the start of combustion can significantly reduce NO_x emissions from a diesel engine. The effect of injection timing on emissions and performance is well established.[14,15,16,17] Delaying the start of combustion by retarding injection timing aligns the heat release from the fuel combustion with the portion of the power (or combustion) stroke of the engine cycle after the piston has begun to move down. This means that the cylinder volume is increasing and that work (and therefore heat) is being extracted from the hot gases. The removal of this heat through expansion lowers the temperature in the combustion gases. NO_x is reduced because the premixed burning phase is shortened and because cylinder temperature and pressure are lowered. Timing retard typically increases HC, CO, PM, and fuel consumption because the end of injection comes later in the combustion stroke where the time for extracting energy from fuel combustion is shortened and the cylinder temperature and pressure are too low for more complete oxidation of PM. This can be offset by increasing injection pressure, allowing an earlier end of injection at the same torque output (i.e., shorter injection duration for the same quantity of fuel injected), and by using multiple injection events following the primary diffusion-combustion event to enhance soot oxidation (see 4.2.2.6 High Pressure Injection, Fuel injection Rate Shaping, Multiple Injections and Induced Charge Motion). We expect that these strategies will continue to be used to meet our proposed remanufactured engine standards and our proposed Tier 3 locomotive and marine diesel engine standards.

4.2.2.5 Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) reintroduces or retains a fraction of the exhaust gases in the cylinder. Most highway diesel engine manufacturers used cooled external EGR to meet the 2004 and later Heavy-Duty Highway emission standards of 2.5 g/bhp-hr HC + NO_x and 0.10 g/bhp-hr PM. EGR has been a key technology used to reduce engine-out NO_x emissions to near 1.0 g/bhp-hr for CDPF-equipped 2007 heavy-duty truck and bus engines in the U.S. Although the use of EGR will not be needed to meet the Proposed Tier 3 locomotive and marine standards or remanufactured engine standards, we expect that some Category 1 marine diesel engines and high-speed locomotive switch engines that are based on Tier 3 and Tier 4 nonroad engine families that already use EGR may also use EGR for their marine or switch locomotive applications of these engines to provide additional engine calibration flexibility.

The use of EGR decreases NO_x formation in three different ways:

1. EGR can thermally reduce peak combustion temperature. Increasing the mass of the cylinder contents by increasing carbon dioxide (CO_2) and water vapor concentrations reduces peak cylinder temperatures during combustion.[18]

2. A fraction of the air within the cylinder is replaced with inert exhaust, primarily CO_2 and water vapor. This reduces the amount of molecular oxygen available for dissociation into atomic oxygen, an important step in NO_x formation via the Zeldovich mechanism.[9]

3. The high temperature dissociation of CO_2 and water vapor is highly endothermic, and thus can reduce temperatures via absorption of thermal energy from the combustion process.[19]

EGR often is routed externally from the exhaust system to the induction system. The use of externally plumbed EGR can increase the intake manifold temperature substantially. This reduces intake charge density and lowers the fresh air/fuel ratio for a given level of turbocharger boost pressure. The result can be a large increase in PM emissions if the boost pressure cannot be increased to compensate for the lower intake charge density. For this reason, external EGR systems typically cool the exhaust gases using a heat exchanger in the exhaust recirculation loop. The introduction of ultra low sulfur diesel fuel substantially reduces the risk of sulfuric acid condensation within an EGR cooler. EGR can also be accomplished entirely in-cylinder (internal EGR) through the use of camshaft phasing or other electronically controlled variable geometry valve-train systems, particularly when applied to varying two-stroke diesel engine exhaust scavenging, although it's use is limited by the inability to effectively cool the residual gases in-cylinder. For both internal and external EGR systems, the EGR rate is electronically controlled to prevent temporary, overly fuel-rich conditions that can lead to high PM emissions during transient engine operation.

Although we don't expect that EGR will be required to meet our proposed remanufacturing standards or our proposed Tier 3 locomotive and marine standards, we do believe that EGR is an effective emissions control strategy that could be selected by an engine manufacturer as a means to control NO_x emissions. EGR may also provide increased flexibility in how engines are calibrated to meet emissions standards with the potential for improvement in part-load fuel consumption.

4.2.2.6 High Pressure Injection, Fuel injection Rate Shaping, Multiple Injections and Induced Charge Motion

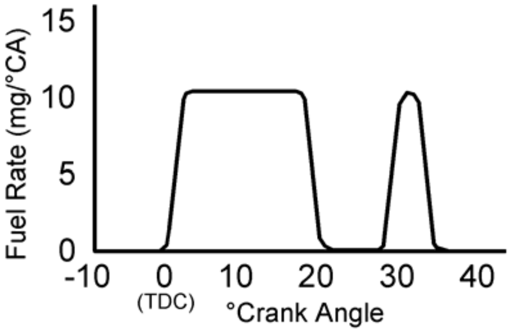
Inducing turbulent mixing is one means of increasing the likelihood of soot particles interacting with oxidants within the cylinder to decrease PM emissions. Turbulent mixing can be induced or increased by a number of means including:

- Changes to intake port/valve design and/or piston bowl design
- Increased (high) injection pressure
- Multiple/split injections using high pressure common rail injection or late post injection using electronic unit injection

As diesel fuel is injected into the cylinder during combustion, the high pressure fuel spray causes increased motion of the air and fuel within the cylinder. This increased motion leads to greater air and fuel interaction and reduced particulate matter emissions. Increasing fuel injection pressure increases the velocity of the fuel spray and therefore increases the mixing introduced by the fuel spray.

The most recent advances in fuel injection technology are high-pressure common rail injection systems with the ability to use rate shaping or multiple injections to vary the delivery of fuel over the course of a single combustion event. These systems are in widespread use in heavy-duty on-highway diesel engines, and they are used in many current nonroad diesel engines. These systems provide both NO_x and PM reductions. Igniting a small quantity of fuel early limits the rapid increase in pressure and temperature characteristic of premixed combustion and its associated NO_x formation. Injecting most of the fuel into an established flame then allows for a steady burn that limits NO_x emissions. Rate shaping may be done either mechanically or electronically. Rate shaping has been shown to reduce NO_x emissions by up to 20 percent.[20] Multiple injection/split injection have also been shown to significantly reduce particulate emissions, most notably in cases that use retarded injection timing or a combination of injection timing retard and EGR to control NO_x.[21,22,23,24] The typical diffusion-burn combustion event is broken up into two events. A main injection is terminated, and then followed by a short dwell period with no injection, which is in turn followed by another short post-injection event, see Figure 4-5. The second pulse of injected fuel induces late-combustion turbulent mixing. The splitting of the injection event into two events aids in breaking up and entraining the “soot cloud” formed from the first injection event into the bulk cylinder contents.

Figure 4-5: An example of using multiple fuel injection events to induce late-combustion mixing and increase soot oxidation for PM control (Adapted form Pierpont, Montgomery and Reitz, 1995).

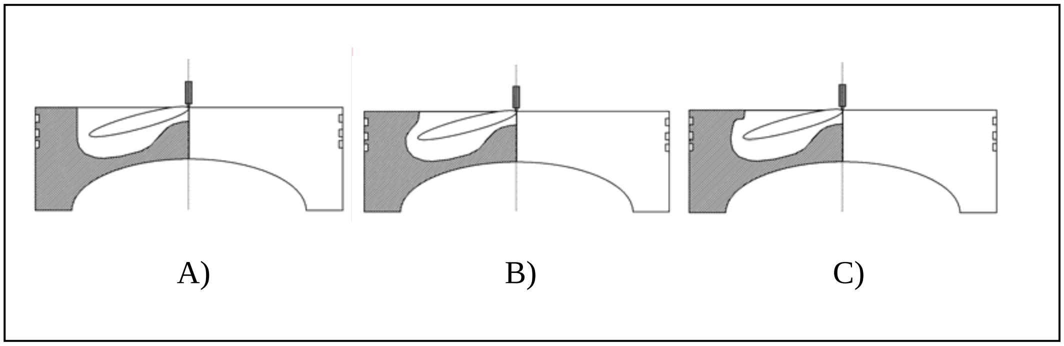


Increasing the turbulence of the intake air entering the combustion chamber (i.e., inducing swirl) can also reduce PM by improving the mixing of air and fuel in the combustion chamber. Historically, swirl was induced by routing the intake air to achieve a circular motion in the cylinder. Heavy-duty on-highway and nonroad engine manufacturers are increasingly using variations of "reentrant" piston designs in which the top surface of the piston is cut out to allow fuel injection and air motion in a smaller cavity in the piston to induce additional turbulence (Figure 4-6). Manufacturers have also changed to three or four valves per cylinder for on-highway and nonroad high-speed diesel engines, and to four valves per cylinder for medium-speed locomotive engines, which reduces pumping losses and can also allow for additional intake air charge motion generation. This valve arrangement also offers better positioning of the fuel injector by allowing it to be placed in-line with the centerline axis of the piston.

At low loads, increased swirl reduces HC, PM, and smoke emissions and lowers fuel consumption due to enhanced mixing of air and fuel. NO_x emissions might increase slightly at low loads as swirl increases. At high loads, swirl causes slight decreases in PM emissions and fuel consumption, but NO_x may increase because of the higher temperatures associated with enhanced mixing and reduced wall impingement.[25] A higher pressure fuel system can be used to offset some of the negative effects of swirl, such as increased NO_x, while enhancing positive effects like increased PM oxidation. Intake air turbulence such as “swirl” can be induced using shrouded intake valves or by use of a helical-shaped air intake port. Swirl is important in promoting turbulent mixing of fuel and soot with oxidants, but can also reduce volumetric efficiency.

Piston bowl design can be used to increase turbulent mixing. Reentrant bowl designs induce separation of the flow over the reentrant “ledge” of the piston and help to maintain swirl through the compression stroke and into the expansion stroke.[9]

Figure 4-6: Schematic examples of a straight-sided piston-bowl (A), a reentrant piston bowl (B), and a deep, square reentrant piston bowl (C) for high-speed diesel engines.



To meet our locomotive remanufactured engine standards and potential marine remanufactured engine standards, we expect that manufacturers will use high pressure electronically controlled unit injection and improvements to piston bowl design. To meet the Tier 3 locomotive and marine standards, we expect that manufacturers of high-speed Category 1 and 2 marine diesel engines, high-speed switch locomotive engines and some Category 2 marine and locomotive medium speed engines will use advanced electronic fuel systems, including in many cases high-pressure common rail fuel injection systems.

4.2.2.7 Reduced Oil Consumption

Reducing oil consumption not only decreases maintenance costs, but also VOF and PM emissions. Reducing oil consumption has been one of the primary ways that heavy-duty truck diesel engines have complied with the 1994 U.S. PM standard. Reducing oil consumption also reduces poisoning of exhaust catalysts from exposure to zinc and phosphorous oil additives.

Redesign of the power assembly (pistons, piston rings and cylinder liner) played an important role in reducing organic carbon PM emissions from locomotive engines in order to meet the Tier 2 locomotive standards. Piston rings can be designed to improve the removal of oil from the cylinder liner surface and drainage back into the crankcase, reducing the amount of oil consumed. Valve stem seals can be used to reduce oil leakage from the lubricated regions of the engines valve train into the intake and exhaust ports of the engine. Improvements to the closed-crankcase ventilation systems that incorporate drain-back to the crankcase of oil separated from the crankcase flow and the use of high-efficiency filtration, either with replaceable high-efficiency coalescing filters or multiple-disc inertial separation, will reduce oil consumption and can remove oil-aerosol from the crankcase flow sufficiently to allow introduction of the crankcase gases into the turbocharger compressor inlet with little or no fouling of the turbocharger compressor, aftercooler or the remainder of the induction system. Euro IV and U.S. 2004 and 2007 heavy-duty truck engine designs that incorporate these technologies have significantly reduced engine-out organic carbon PM emissions.

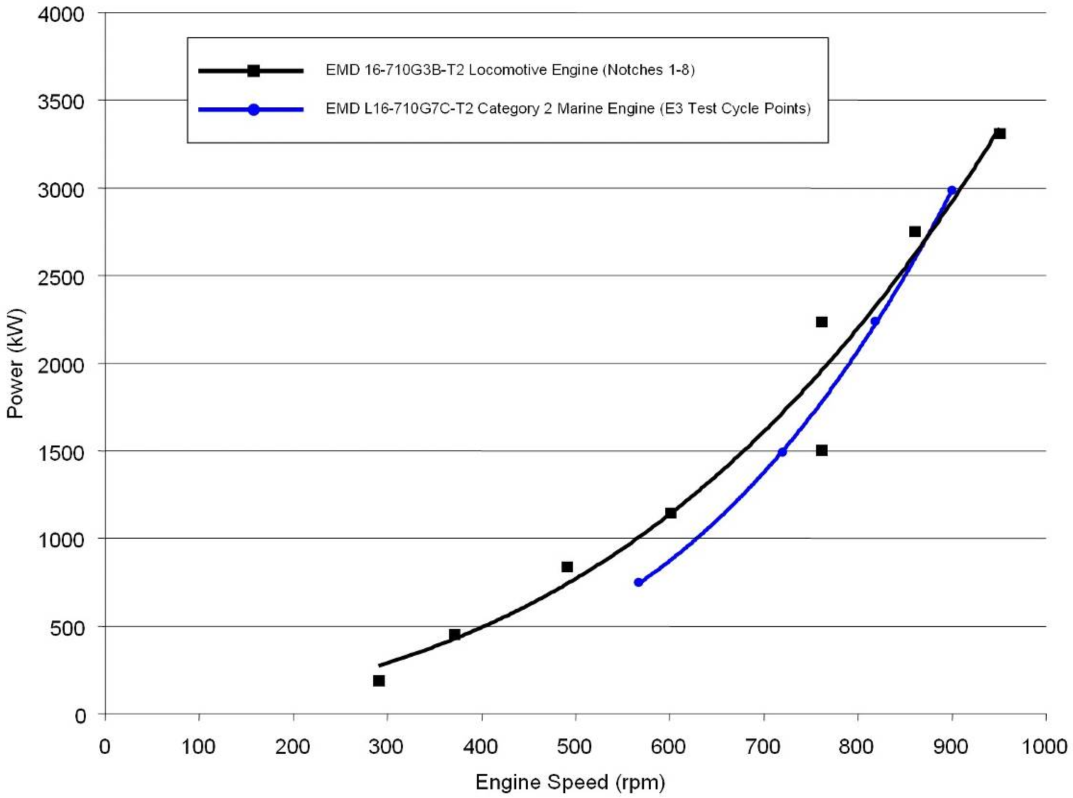
Particularly in the case of medium-speed engines, which have a relatively high fraction of PM emissions due to organic carbon PM, reduced oil consumption will be an effective means of meeting our proposed remanufactured locomotive engine and Tier 3 locomotive and marine PM standards. We expect Tier 0 and Tier 1 remanufactured locomotive engines to receive power assembly designs similar to those of current Tier 2 locomotives. We expect that remanufactured Tier 2 locomotive engines and new Tier 3 locomotive and marine engines will receive incremental improvements in the design of the power assembly, valve stem seals and improved crankcase ventilation systems—especially if the crankcase ventilation system routes the crankcase vent to the turbocharger inlet and incorporates high-efficiency oil separation from the crankcase flow. When applying catalytic exhaust controls to meet the Tier 4 standards, reduced oil consumption will improve the durability of catalyst systems by reducing their exposure to zinc- and phosphorous-containing oil additives.

4.2.2.8 Application Specific Differences in Emissions and Emissions Control

In much of the preceding discussion we have relied on previous experience primarily from high-speed (approximately >1600 rpm rated speed) on-highway and nonroad engines to provide specific examples of emissions formation and engine-out emissions control. There are, however, some important operational and design differences between these engines and locomotive and marine diesel engines, particularly the medium speed locomotive and marine engines.

High-speed diesel engines used in on-highway and nonroad applications (with the exception of generator applications) undergo significant transient operation that can create temporary conditions of insufficient availability of oxidants due to the inability of the air-supply from the turbocharger to follow engine transients. For these applications, the majority of elemental carbon PM is emitted during these transients of insufficient oxygen availability. Such transients are greatly reduced in locomotive and marine applications. Marine propulsion engines operate primarily along a propeller curve that effectively forms a narrower outer boundary within which engine operation occurs. Marine generators and locomotive engines operate within even narrower bounds. Generators generally operate at close to a fixed engine speed with varying load. Locomotives operate at 8 distinct speed-load operational notches with gradual transitions between each notch. Figure 4-7 illustrates the speed and power ranges over which typical locomotives and marine engines operate.

Figure 4-7: A comparison engine power output versus engine speed for a locomotive engine operated over notches one through eight and for a Category 2 marine engine operated over the E3 marine cycle, which approximates a propeller curve with a cubic relationship between speed and load. A cubic fit through the locomotive notch points is remarkably similar to the E3 prop-curve. The specific example shown is for two similar versions of the EMD two-stroke medium-speed diesel engine.



In addition to operational differences, medium-speed diesel engines (750 to 1200 rpm rated speed) are the predominant type used in Category 2 marine and line-haul locomotive applications. Medium-speed diesel engines are also predominant in older switch locomotives, although the majority of locomotive switch families certified to the Tier 2 locomotive standards now use high-speed diesel engines. Medium speed diesel engines typically have even lower elemental carbon PM emissions due to increased residence time available at high load conditions for late-cycle burn-up of elemental carbon PM as compared to high-speed diesel applications such as heavy-duty on-highway engines. The increased duration of combustion also increases NO_x formation for medium-speed diesel engines.

Large-bore locomotive and Category 2 medium speed diesel engines also have significantly higher lubricating oil consumption than many high-speed diesel engines. Lubricating oil consumption for current 2007 on-highway diesel truck engines is approximately 0.09 to 0.13% of fuel consumed versus approximately 0.30 to 0.35% for 2-stroke medium-speed diesel locomotive and marine engines and approximately 0.25% for 4-stroke medium-speed locomotive engines. To some degree, this higher consumption of lubricating oil is by design. Higher lubricating oil consumption allows for a reduced frequency of complete oil changes, while at the same time the resulting frequent topping off of oil replenishes lubricant additives that maintain the lubricating oil's total base number (TBN) to prevent acidic corrosion. Frequent topping off also maintains the oil's oxidation stability to maintain oil viscosity. Because improvements in high-pressure fuel injection systems and electronic engine management were used to reduce carbon PM emissions to meet Tier 2 locomotive and marine engine PM standards, only moderate improvements in lubricating oil consumption were necessary to meet the Tier 2 PM emission standards. This reduced elemental carbon PM, coupled with still moderately high lubricating oil consumption, results in a PM composition of medium-speed diesel engines that is substantially different than that of on-highway diesel engines and many nonroad diesel engines. PM emissions from medium-speed diesel engines are dominated by organic carbon PM emissions, with the relative contributions of organic carbon and elemental carbon PM to total PM approximately reversed from those of on-highway and most non-road diesel engines. Figure 4-8 shows the relative contributions of elemental carbon, organic carbon, and sulfate PM emission from recent tests of Tier 0, Tier 1 and Tier 2 locomotives.

Another difference is that crankcase ventilation flow is considerably higher from very large displacement medium-speed diesel engine compared with smaller, high-speed engines. This has complicated the design of crankcase ventilation systems with effective oil-aerosol separation. Higher capacity, high efficiency inertial disc-type separators are now being introduced in medium-speed marine applications to reduce bilge water contamination and oil consumption. Inertial disc-type oil separators originally developed for Euro IV and 2007 U.S. Heavy-duty On-highway applications have provided sufficient oil separation to allow introduction of filtered crankcase gases into the turbocharger inlet without oil fouling of the turbocharger or aftercooler system. Similar systems are now optionally available on Wärtsilä medium-speed stationary generator and marine engines (Figure 4-9). We expect that similar systems will be used on Tier 3 and Tier 4 Category 2 marine engines and remanufactured Tier 2 and new Tier 3 and Tier 4 locomotive systems.

Improvements in oil formulation, including switching from Group 1 to Group 2 base oils with greatly improved oxidation stability also reduce the need for oil top-off to replenish lubricant additives. As Group 1 become unavailable in Europe, we expect increased use of Group 2 base oil formulations for use with EMD medium-speed engines in Europe. Future reductions in fuel sulfur for Tier 3 and Tier 4 locomotive and marine engines will also reduce the need for TBN control.

Figure 4-8: Emissions for 6 locomotives tested using 3000 ppm sulfur nonroad diesel fuel.

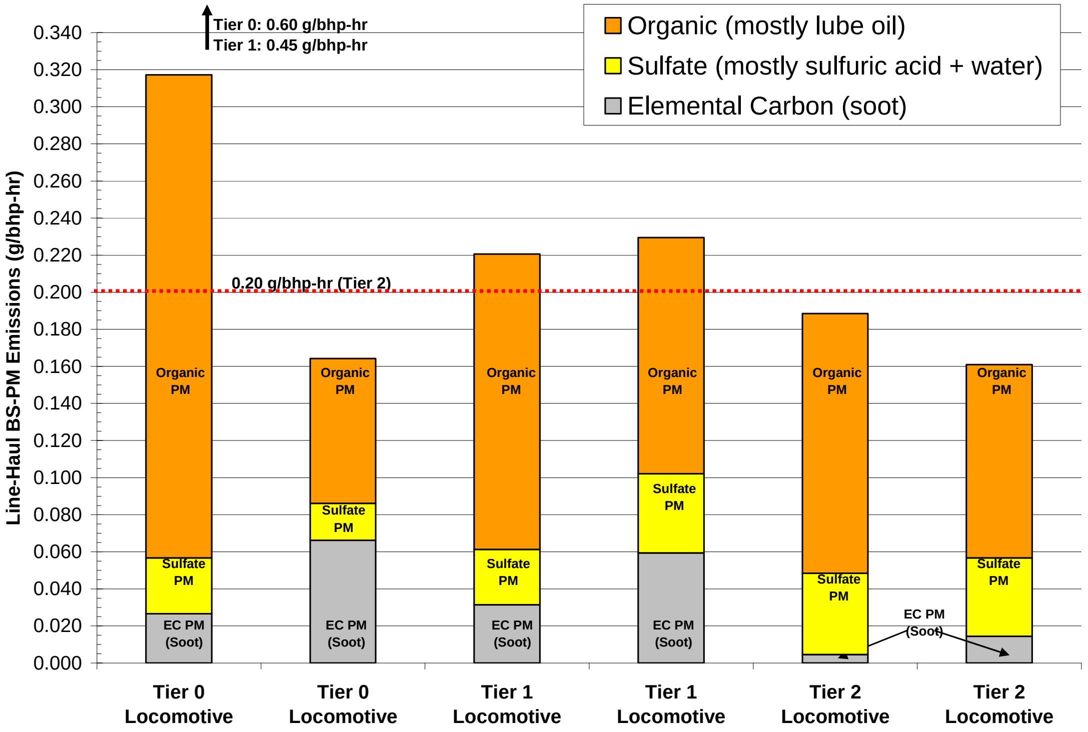
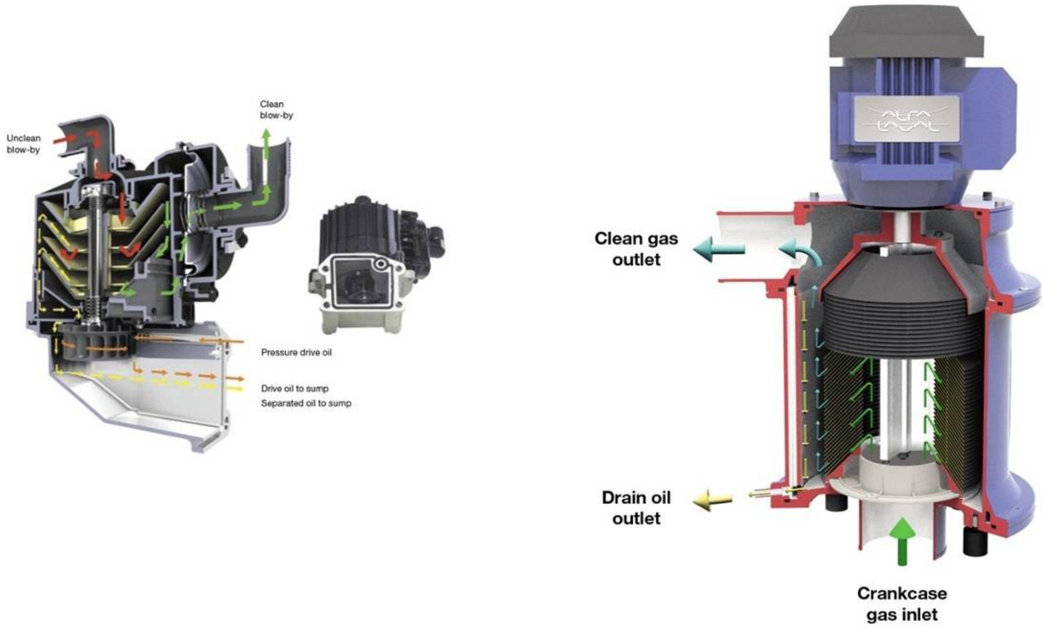


Figure 4-9: Alfa Laval disc-type inertial oil-aerosol separation systems for use with closed crankcase ventilation systems. The unit on the left is Alfdex system originally developed for Euro IV and U.S. 2007 heavy-duty on-highway applications. This system was designed as "fit for life", or essentially maintenance free for the useful life of the engine. A much higher volume system (right) was recently developed for Wärtsilä medium-speed engines.



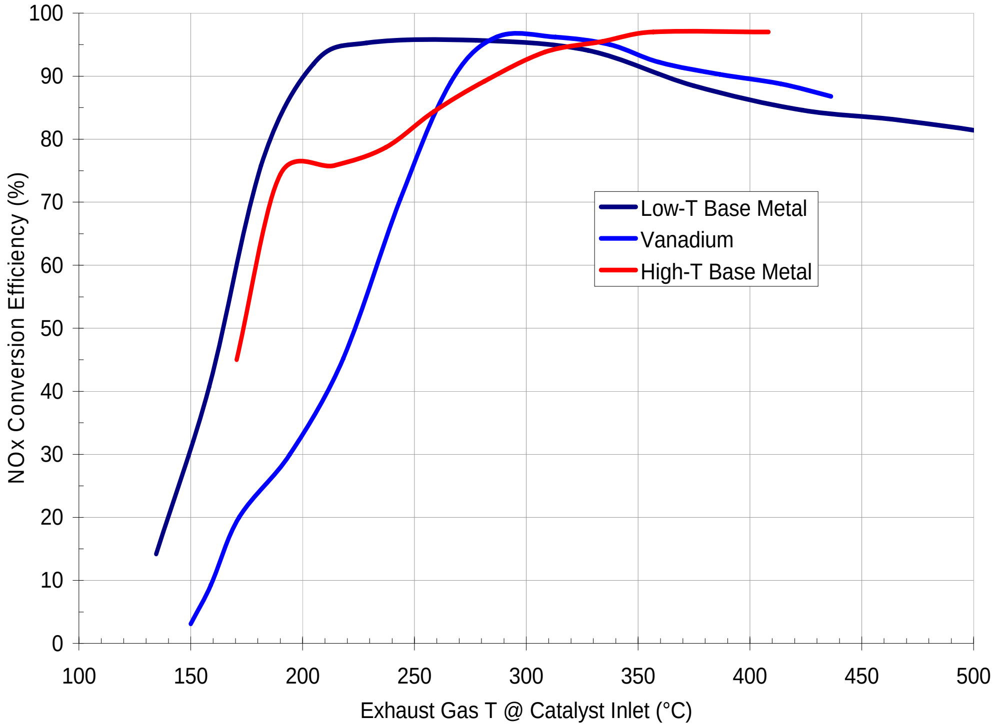
4.3 Feasibility of Tier 4 Locomotive and Marine Standards

In this section we describe the emissions control technologies that we believe may be used to meet our proposed Tier 4 locomotive and marine diesel engine standards. In general, these technologies involve the use of catalytic exhaust treatment devices placed in an engine's exhaust system, downstream of an engine's exhaust manifold or turbocharger turbine outlet. The catalytic coatings of these aftertreatment devices are oftentimes sensitive to other constituents in diesel exhaust. For example, sulfur compounds within diesel fuel can decrease the effectiveness or useful life of a catalyst. For this reason, we will require the use of ultra-low sulfur diesel fuel in engines that will be designed to meet our proposed Tier 4 emissions standards. We also expect that engine manufacturers will specify new lubricating oil formulations for these Tier 4 engines because of other trace compounds in some currently used lubricating oils,. These new oil formulations will help ensure that catalytic exhaust aftertreatment devices will operate properly throughout their useful life. Because we have already finalized and begun implementation of similar aftertreatment-forcing standards for both heavy-duty on-highway and nonroad diesel engines, we are confident that the application of similar, but appropriately designed, aftertreatment systems for locomotive and marine applications is technologically feasible, especially given the implementation timeframe that we are proposing.

4.3.1 Selective Catalytic Reduction (SCR) NO_x Control Technology

Recent studies have shown that an SCR system is capable of providing well in excess of 80% NO_x reduction efficiency in high-power, heavy-duty diesel applications.[26, 27, 28] As shown in Figure 4-10, Vanadium and base-metal (Cu or Fe) SCR catalysts can achieve significant NO_x reduction throughout much of exhaust gas temperature operating range observed in heavy-duty diesel engines used in locomotive and marine applications. Collaborative research and development activities between diesel engine manufacturers, truck manufacturers, and SCR catalyst suppliers have also shown that SCR is a mature, cost-effective solution for NO_x reduction on heavy-duty diesel engines. While many of the published studies have focused on heavy-duty highway truck applications, similar trends, operational characteristics, and NO_x reduction efficiencies have been reported for heavy-duty marine and stationary electrical power generation applications as well.[29] An example of the performance capability of SCR in marine applications is the Staten Island Ferry *Alice Austen.* This demonstration project reports that 90-95% NO_x reduction is possible under steady-state conditions (where the exhaust gas temperature is above 270 °C.)[30] Given the preponderance of studies and data - and our analysis summarized here - we believe that this technology is appropriate for both locomotive and marine diesel applications.

Figure 4-10: SCR Catalyst NO_x Reduction versus Exhaust Gas Temperature Using an Ammonia-to-NO_x Ratio of 1:1[31,32,B]



An SCR catalyst reduces nitrogen oxides to N_2 and water by using ammonia (NH_3) as the reducing agent. The most-common method for supplying ammonia to the SCR catalyst is to inject an aqueous urea-water solution into the exhaust stream. In the presence of high-temperature exhaust gasses (>200 °C), the urea hydrolyzes to form NH_3 and CO_2 - the NH_3 is stored on the surface of the SCR catalyst where it is used to complete the NO_x-reduction reaction. In theory, it is possible to achieve 100% NO_x conversion if the NH_3-to-NO_x ratio (α) is 1:1 and the space velocity within the catalyst is not excessive (i.e. there is ample time for the reactions to occur). However, given the space limitations in packaging exhaust aftertreatment devices in mobile applications, an α of 0.85-1.0 is often used to balance the need for high NO_x conversion rates against the potential for NH_3 slip (where NH_3 passes through the catalyst unreacted). Another approach to prevent NH_3 slip is to use an oxidation catalyst downstream of the SCR. This catalyst, also referred to as a slip catalyst, is able to oxidize the NH_3 which passes through (or is released from) the SCR. When this approach is used, it is possible to operate the SCR system at near-peak efficiency by optimizing the urea dosing rate to accomplish high NO_x control (which provides

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[B] The “High-T Base Metal” curve is based on a composite of low and high-space-velocity data provided by catalyst manufacturers. It is meant to represent high-hour performance of a system at a space velocity of 40,000 hr^{-1}.

adequate NH_3 for NO_x reduction). Any excess NH_3 (ammonia slip) that results from such optimization is converted to N_2 and water in the slip catalyst.

The urea dosing strategy and the desired α are dependent on the conditions present in the exhaust gas; namely temperature and the quantity of NO_x present (which can be determined by engine mapping, temperature sensors, and NO_x sensors). Overall NO_x conversion efficiency, especially under low-temperature exhaust gas conditions, can be improved by controlling the ratio of two NO_x species within the exhaust gas; NO_2 and NO. This can be accomplished through use of an oxidation catalyst upstream of the SCR catalyst to promote the conversion of NO to NO_2. The physical size and catalyst formulation of the oxidation catalyst are the principal factors which control the NO_2:NO ratio, and by extension, improve the low-temperature performance of the SCR catalyst.

Published studies show that SCR systems will experience very little deterioration in NO_x conversion throughout the life-cycle of a diesel engine.[33] The principal mechanism of deterioration in an SCR catalyst is thermal sintering - the loss of catalyst surface area due to the melting and growth of active catalyst sites under high-temperature conditions (as the active sites melt and combine, the total number of active sites at which catalysis can occur is reduced). This effect can be minimized by design of the SCR catalyst washcoat and substrate for the exhaust gas temperature window in which it will operate. Another mechanism for catalyst deterioration is catalyst poisoning - the plugging and/or chemical de-activation of active catalytic sites. Phosphorus from the engine oil and sulfur from diesel fuel are the primary components in the exhaust stream which can de-activate a catalytic site. The risk of catalyst deterioration due to sulfur poisoning will be all but eliminated with the 2012 implementation of ULSD fuel (<15 ppm S) for locomotive/marine applications. Catalyst deterioration due to phosphorous poisoning can be reduced through the use of lubricating oil with low sulfated-ash, phosphorus, and sulfur content (low-SAPS) and through reduced oil consumption (as discussed in 4.2.2.7). Low-SAPS oil will improve the performance of catalyzed-DPF and SCR aftertreatment components in locomotive and marine applications. The high ash content in current locomotive and marine engine oils is related to the need for a high total base number (TBN) in the oil formulation. This high-TBN oil has been necessary because of the high sulfur levels typically present in diesel fuel - a high TBN is necessary to neutralize the acids created when fuel-borne sulfur migrates to the crankcase. With the use of ULSD fuel, acid formation in the crankcase will not be a significant concern. This oil will be available for use in heavy-duty highway engines by October 2006 and is specified by the American Petroleum Institute as "CJ-4." The durability of other exhaust aftertreatment devices, namely the DOC and DPF, will also benefit from the use of ULSD fuel and low-SAPS engine oil - less sulfur and phosphorous will improve DOC effectiveness and less ash will increase the DPF ash-cleaning intervals.

The onboard storage of the aqueous urea solution on locomotives and marine vessels can be accomplished through segmenting of the existing fuel tanks or fitment of a separate stainless steel or plastic urea tank. To assure consistent SCR operation between refueling stops, the volume of urea-water solution carried onboard will need to be at least 5% of the diesel fuel tank capacity. At the appropriate intervals, the crews will need to refill the urea tank. For the railroad and marine industries, the distribution and dispensing of urea is expected to benefit from any solutions put in place by the trucking industry and heavy-duty highway engine and vehicle manufacturers well in advance of the proposed Tier 4 locomotive and marine regulations.

We project that locomotive and marine diesel engine manufacturers will benefit from any development taking place to implement DPF and SCR technologies in advance of the heavy-duty truck NO_x standards in Europe and the U.S. The urea dosing systems for SCR, already in widespread use across many different diesel applications, are expected to become more-refined/robust/reliable in advance of our proposed Tier 4 locomotive and marine standards. Given the steady-state operating characteristics of locomotive and marine engines, DPF regeneration strategies and urea dosing controls will certainly be capable of controlling PM and NO_x at the levels necessary to meet our proposed standards.

4.3.1.1 Urea Infrastructure and Feasibility & Cost

The preferred concentration for the aqueous urea solution is 32.5% urea, which is the eutectic concentration (provides the lowest freezing point and the urea concentration does not change if the solution is partially frozen).[34] With a freezing temperature of -11 °C (12 °F), heaters and/or insulation may be necessary in Northern regions for urea storage/dispensing equipment and the urea dosing apparatus (tank, pump, and lines) on the on the engine. The centralized nature of locomotive and marine refueling from either large centralized fuel storage tanks or from tanker trucks with long-term purchase agreements provides a working example of how urea could also be distributed from storage tanks at centralized fueling facilities, tanker trucks and/or multi-compartment fuel-oil/urea tanker trucks at remote fueling sites. Given that only a small percentage of the locomotive and marine fleet will require urea prior to 2017, EPA believes that the infrastructure for supplying urea from centralized refueling points and tank trucks can be established to serve the rail and marine industries. Discussions concerning the urea infrastructure and specifications for an emissions-grade urea solution are beginning to take place amongst stakeholders in the light-duty and heavy-duty highway diesel industry. It is possible that these discussions will result in a fully-developed urea infrastructure for light-duty and heavy-duty diesel highway engine and vehicle applications by 2010. This would allow seven years to expand and develop this framework to support the needs of the railroad and marine industries. Even without these developments underway in the light-duty and heavy-duty highway industry, the centralized fueling nature of the locomotive and marine industries lends itself well to adaptation to support a supply of urea at their normal fueling locations.

In 2015, urea cost is expected to be ~$0.75/gallon for retail facilities dispensing 200,000 - 1,000,000 gallons/month, and ~$1.00/gallon for those dispensing 80,000 - 200,000 gallons/month.[35] The additional operating cost incurred by the rail industry will also be dependent on the volume of urea dispensed at each facility, with smaller refueling sites experiencing higher costs. It is estimated that 87% of the locomotive fleet is refueled at fixed facilities and 13% at direct truck-to-locomotive facilities.[36] The type of urea storage/dispensing equipment, and the ultimate cost-per-gallon, for railroad and marine industries will depend on the volume of fuel & urea dispensed at each site. High-volume fixed sites may choose to mix emissions-grade dry urea (or urea liquor) and de-mineralized water on-site, whereas others may choose bulk or container delivery of a pre-mixed 32.5% urea-water solution. Again, with the possible implementation of SCR for light-duty and heavy-duty highway applications in 2010, the economic factors for each urea supply option may be well-known prior to implementation of the 2017 standards. Even without these developments underway in the light-duty and heavy-duty highway industry, we believe that the urea supply options for the locomotive and marine industries will be numerous.

Urea production capacity in the U.S. is more than sufficient to meet the additional needs of the rail and marine industries. For example, in 2003, the total diesel fuel consumption for Class I railroads was approximately 3.8 billion gallons.[37] If 100% of the Class I locomotive fleet were to be equipped with SCR catalysts, approximately 190 million gallons-per-year of 32.5% urea-water solution would be required.[35] It is estimated that 190 million gallons of urea solution would require 0.28 million tons of dry urea (1 ton dry urea is needed to produce 667 gallons of 32.5% urea-water solution).[35] Currently, the U.S. consumes 14.7 million tons of ammonia resources per year, and relies on imports for 41% of that total (of which, urea is the principal derivative). In 2005 domestic ammonia producers operated their plants at 66% of rated capacity, resulting in 4.5 million tons of reserve production capacity.[38] In the hypothetical situation above, where 100% of the locomotive fleet required urea, only 6.2% of the reserve domestic capacity would be needed to satisfy the additional demand. A similar analysis for the marine industry, with a yearly diesel fuel consumption of 2.2 billion gallons per year, would not significantly impact the urea demand-to-reserve capacity equation. Since the rate at which urea-SCR technology is introduced to the railroad and marine markets will be gradual, the reserve urea production will be adequate to meet the expected demand in the 2017 timeframe of the proposed Tier 4 standards.

4.3.1.2 Establishing the Tier 4 NO_x Standard

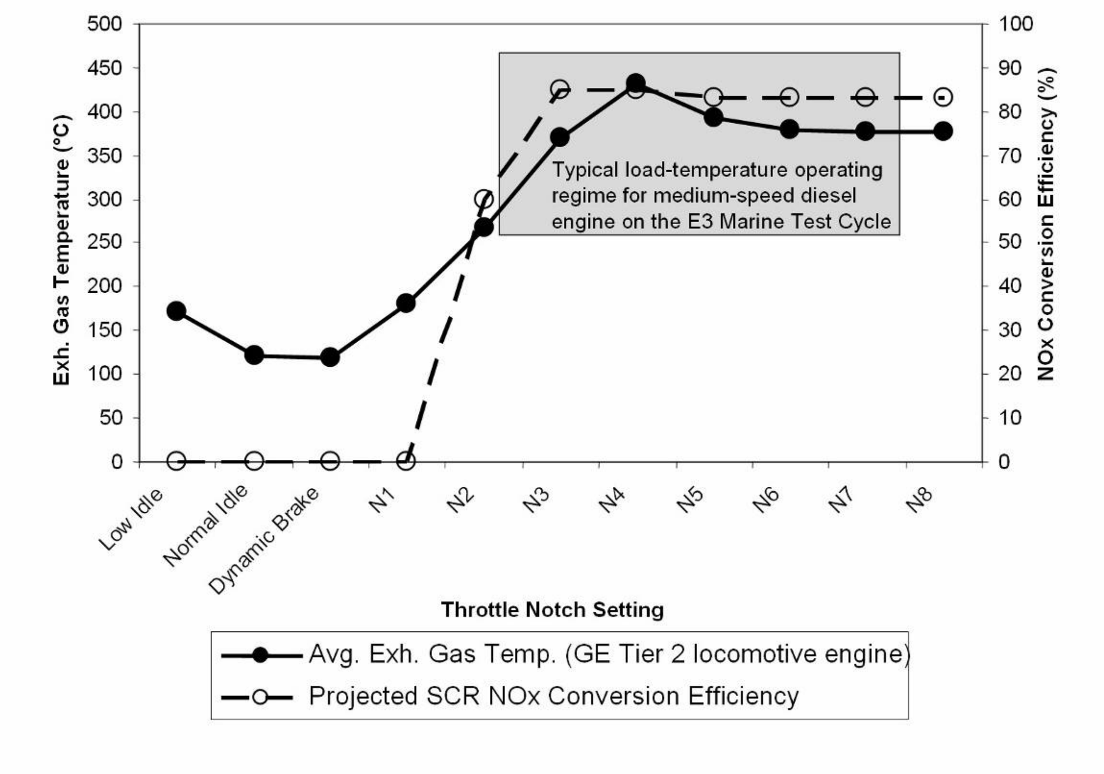
The basis for the proposed locomotive Tier 4 Line-Haul NO_x standard is the Tier 3 NO_x emission standard (5.5 g/bhp-hr) reduced by the following SCR catalyst efficiency estimates at full useful life of the engine; 60% efficiency in operating mode notch 2 (where exhaust gas temperature is near the minimum-level for NO_x conversion), 85% conversion efficiency in operating modes notches 3 and 4 (where lower catalyst space velocities allow optimum reaction rates), and 83% conversion efficiency in the high-load operating modes, notches 5 through 8.[C] When these efficiencies are weighted according to the line-haul duty cycle emissions test, an overall NO_x reduction of 78% is obtained.

Figure 4-11 illustrates EPA's projection of an "aged" locomotive/marine SCR system at full useful life. When these levels of NO_x reduction are applied to engine out emissions from a typical Tier 2, 4-stroke-cycle locomotive diesel engine producing 5.5 g/bhp-hr of NO_x on the line-haul duty cycle, the worst-case, full useful life standard is established at 1.3 g/bhp-hr.[D] This standard includes a compliance margin and we expect that emissions of a new engine – and the emissions throughout much of the engine's life – will be closer to 0.8 g/bhp-hr. Because marine diesel engines will also operate under similar engine load/exhaust gas temperature conditions over their respective cycles, they also will be capable of similar NO_x reductions. As shown in the shaded area of Figure 4-11, the E3 Marine Test Cycle lies within the peak performance range of an SCR catalyst.

[C] For conditions present in Tier 0-2 locomotives, SCR operation (and hence, NO_x reduction) is not possible at the low power notches (NI, LI, DB, and N1) due to low exhaust gas temperatures.

[D] With an overall, duty-cycle-weighted, NO_x conversion efficiency of 78%, the remainder NO_x emissions will be 22% of the engine-out level (i.e. the Tier 2 Standard is 5.5 g/bhp-hr; 5.5 x 0.22 = 1.2 g/bhp-hr).

Figure 4-11: Typical 4-Stroke Diesel Locomotive Exhaust Gas Temperatures and Projected SCR Catalyst Efficiency at Full Useful Life.



For applications requiring improved SCR performance at lower exhaust gas temperatures, several options are available; throttling the engine airflow to increase exhaust gas temperature, using an SCR formulation designed for the low-temperature NO_x conversion, or a heated urea dosing system (or some combination of all three options). Throttling of the intake airflow on refuse trucks – which often operate under light-load conditions - has been shown to substantially increase exhaust gas temperatures.[39] Increasing the exhaust gas temperature at light load not only provides an opportunity for extended SCR operation, it is also improves performance of the DOC and DPF components. Low-temperature NO_x conversion can also be enhanced by use of a base-metal (Fe or Cu) zeolite SCR catalyst (see Figure 4-12). Systems for dosing urea at exhaust temperatures below 250 °C are being developed for heavy-duty, highway truck applications. One such system utilizes an electrically-heated bypass to hydrolyze the urea-water solution and produce NH3 when exhaust gas temperatures are as low as 160 °C – providing an additional 5-25% NO_x reduction relative to a system which stops urea dosing at 250 °C.[40] Use of a pre-turbocharger location for a DOC located upstream of the SCR system can also improve low temperature performance by driving NO to NO_2 conversion at lighter engine loads than would be possible with more remote mounting of the DOC. Use of air-gap or other types of insulated construction for exhaust system components can also improve thermal management and increase exhaust gas and catalyst temperatures. For further discussion of manifold-mounting of the DOC and exhaust system thermal management, see section 4.3.2 PM and HC Exhaust Aftertreatment Technology.

If no improvements were made to technologies which exists today, the 1.3 g/bhp-hr locomotive standard is technologically feasible. With projected improvements (that are currently more-difficult to quantify), we are confident in-use operation and end of useful life NO_x emission levels will be less than the 1.3 g/bhp-hr standard proposed in this rulemaking.

4.3.2 PM and HC Exhaust Aftertreatment Technology

The most effective exhaust aftertreatment used for diesel PM emissions control is the diesel particulate filter (DPF). More than a million light diesel vehicles that are OEM-equipped with DPF systems have been sold in Europe, and over 200,000 DPF retrofits to diesel engines have been conducted worldwide.[7] Broad application of catalyzed diesel particulate filter (CDPF) systems with greater than 90% PM control is beginning with the introduction of 2007 model year heavy-duty diesel trucks in the United States. These systems use a combination of both passive and active soot regeneration. CDPF systems utilizing metal substrates are a further development that trades off a degree of elemental carbon soot control for reduced backpressure, greater design and packaging flexibility, improvements in the ability of the trap to clear oil ash, and better scaling to the large sizes needed for locomotive and marine applications. Metal-CDPFs were initially introduced as passive-regeneration retrofit technologies for diesel engines designed to achieve approximately 50 to 60% control of PM emissions.[41] Recent data has shown that metal-CDPF trapping efficiency for elemental carbon PM can exceed 70% for engines with inherently low elemental carbon emissions.[42] Data from locomotive testing (Figure 4-12) confirms a relatively low elemental carbon fraction and relatively high organic fraction for PM emissions from medium-speed Tier 2 locomotive engines.[43] The use of a highly oxidizing PGM catalyst coated directly to the CPDF combined with a highly oxidizing DOC mounted upstream of the CDPF would provide 95% or greater removal of HC, including the semi-volatile organic compounds that contribute to PM.

A functional schematic of a metal-CDPF is shown in Figure 4-13. In this particular example, flow restrictions divert a portion of the particle laden exhaust flow through the porous sintered metal walls. The openings in the flow restrictions are sufficient to allow accumulated ash to migrate through the CDPF substrate, either reducing or eliminating the need for periodic ash cleaning.[44] The metal-CDPF will most likely be used in combination with an upstream diesel oxidation catalyst (DOC). A diesel oxidation catalyst mounted upstream of the metal-CDPF improves NO to NO_2 oxidation for both passive soot regeneration within the CDPF and to increase the NO_x reduction efficiency of the SCR system, particularly during light-load and/or under cold ambient conditions. The DOC would also assist with oxidation of organic carbon PM, particularly at lower notch positions. The DOC effectively becomes mass transport limited for NO_2 oxidation at notch 6 and above (approximately $80{,}000^{-hr}$ space velocity), but at that point exhaust temperatures at the location of the metal-CDPF would be sufficient for NO to NO_2 oxidation and thus for passive soot regeneration and also for oxidation of organic carbon. Some or all of the DOC volume can be installed in a close-coupled position within the exhaust manifold, immediately downstream of the exhaust ports and upstream of the turbocharger's exhaust turbine (Figure 4-14) and within the “vee” of V-type locomotive and marine engines. Air-gapped construction can be used to provide faster warm-up and retention of heat within exhaust components. Thermal insulation that is similar to what is already in common use with dry exhaust manifold configurations in Category 2 marine applications can be used to increase exhaust and catalyst temperatures (Figure 4-15).

Figure 4-16 shows the expected line-haul locomotive PM reductions for:

- A 4-stroke line-haul Tier 2 locomotive due to reducing fuel sulfur content to 15 ppm
- A 4-stroke line-haul Tier 3 locomotive with oil consumption reduced approximately 50% relative to Tier 2 via improvements to the power assembly and closed-crankcase ventilation system
- A 4-stroke line-haul Tier 4 locomotives with application of a DOC and metal-CDPF to the Tier 3 engine
- A 4-stroke line-haul Tier 4 locomotives with application of a DOC and wall-flow-CDPF to the Tier 3 engine

Figure 4-17 shows the expected PM reductions over the E3 General Marine Duty Cycle for:

- A 2-stroke medium-speed Category 2 marine diesel engine due to reducing fuel sulfur content to 15 ppm[E]
- A 2-stroke medium-speed Category 2 marine diesel engine with oil consumption reduced approximately 50% relative to Tier 2 via improvements to the power assembly and closed-crankcase ventilation system
- A 2-stroke medium-speed Category 2 marine diesel engine with application of a DOC and metal-CDPF to the Tier 3 engine

Due to the relatively high organic carbon fraction and low elemental carbon fraction in the PM emissions, the difference in PM emissions between the metal-

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[E] For this specific example, speciated data from an EMD 16-710G3C-T2 2-stroke medium speed locomotive engine was used. This engine is offered in both Category 2 marine and line-haul locomotive applications. The locomotive application has a slightly higher speed rating and lower NOx emissions. A fit of the data to E3 points for the lower 4000 bhp @ 900 rpm EMD 16-710G7C-T2 marine rating was used to model PM emissions instead of the 4300 bhp @ 950 rpm rating. The G3C-T2 and G7C-T2 engines are remarkably similar, if not identical, designs with very similar NOx and PM emissions and appear to differ only with respect to rated power and rated speed.

CDPF and the wall-flow-CDPF is less than 0.01 g/bhp-hr (approximately 0.005 g/bhp-hr). The advantages of the metal-CDPF relative to the wall-flow-CDPF are greatly reduced maintenance requirements and reduced exhaust back-pressure. We estimate that the use of a metal CDPF would result in PM emissions of approximately 0.02 g/bhp-hr over the line-haul cycle. The results from a ceramic wall-flow trap would be nearly identical at 0.015 g/bhp-hr. This will provide sufficient compliance margin to meet the 0.03 g/bhp-hr Tier 3 line-haul locomotive standard. Because PM emissions concentrations downstream of a PM trap are characteristically flat or relatively constant, we expect very similar PM reductions from marine engines that utilize similar PM trap technology.

Figure 4-18 shows the expected PM removal efficiency of going from Tier 3 to Tier 4 plotted vs. exhaust temperature for all notch positions. The Tier 3 levels were calculated based on a 4-stroke Tier 2 locomotive engine with improved lubricating oil control. The Tier 4 levels were calculated based on the efficiency of a DOC and metal-CDPF combination at the end of useful life and taking into account removal efficiency for elemental and organic carbon and expected sulfate make from fuel and lubricant sulfur. Efficiency is similar or higher for Category 2 marine applications due to a narrower range of exhaust temperatures (approximately 250 °C to 350 °C over the E3 cycle) that are generally above the light-off temperatures for HC and NO oxidation for typical precious-metal DOC and CDPF formulations and yet are largely below the temperatures at which peak sulfate-make occurs.

Figure 4-12: Brake-specific PM emissions speciated into soluble organic, soluble sulfate, and insoluble elemental carbon over the Federal Line-Haul duty cycle.

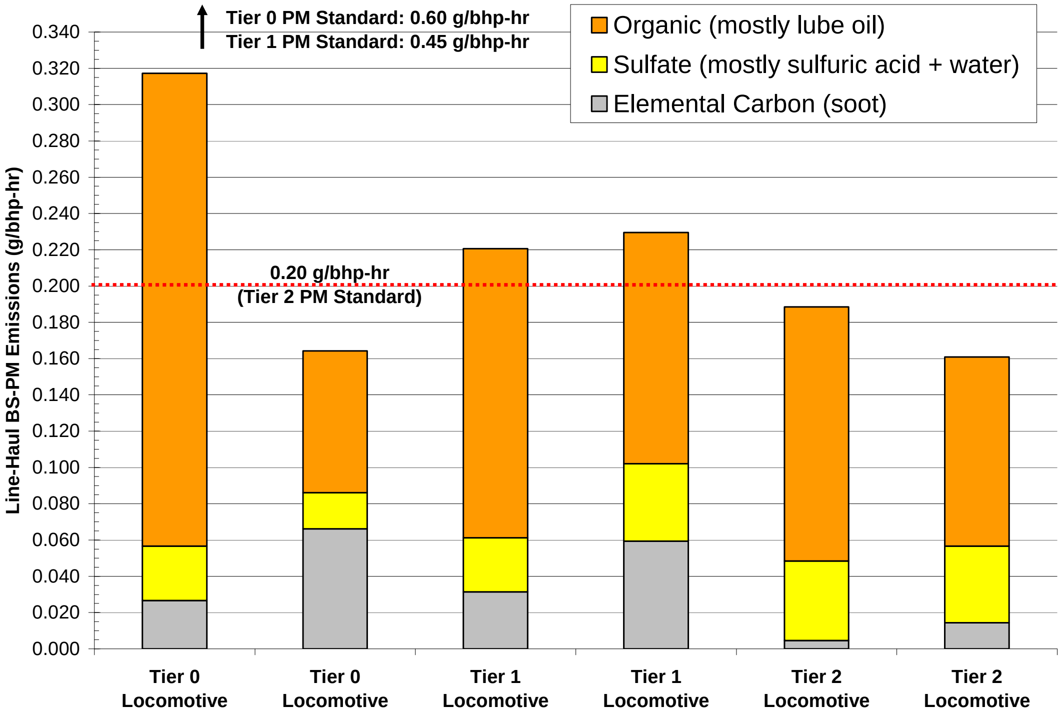


Figure 4-13: Cross-sectional functional schematic for a metal-CDPF (not to scale). Flow restrictions force part of the particle laden exhaust flow through the porous sintered metal layers. High efficiencies are possible at with engines having relatively low elemental carbon PM emissions.

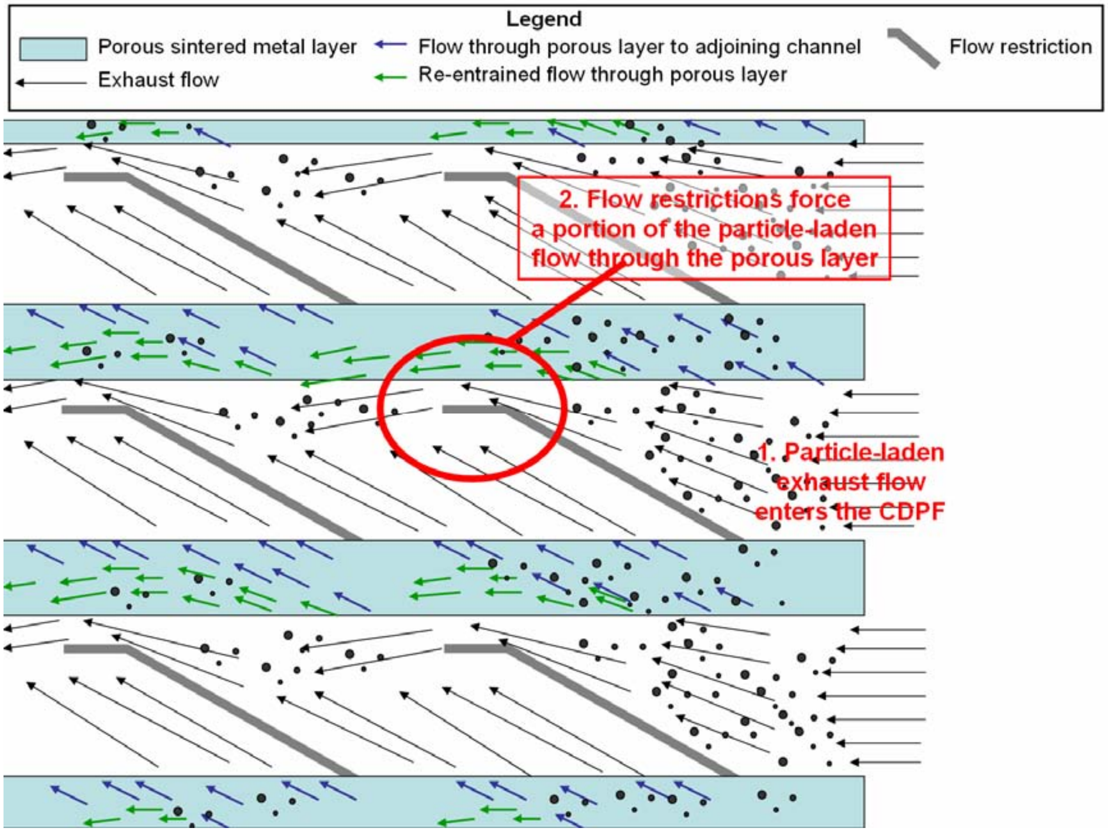


Figure 4-14: Metal-monolith diesel oxidation catalysts (DOC) mounted within the exhaust manifold of an EMD 710-series locomotive diesel engine. Use of a close-coupled DOC extends the range of light-load operation where NO to NO_2 oxidation can occur. Oxidation of engine-out NO to NO_2 assists with passive regeneration of the CDPF and increases the low temperature performance of the urea SCR system. The system also improves oxidation of organic carbon PM at light load conditions (locomotive notches 1 through 6).

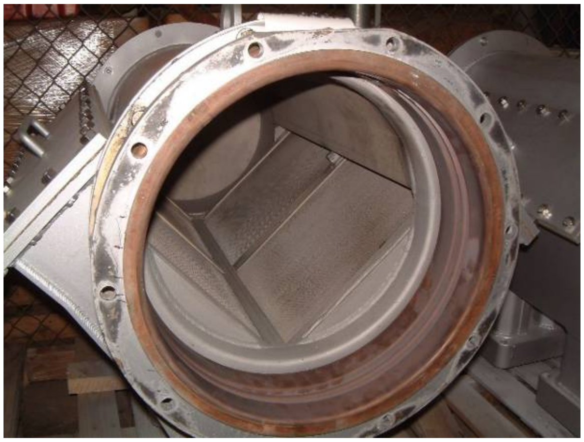


Figure 4-15: A two-stroke medium-speed Category 2 marine diesel engine with an insulated exhaust manifold and exhaust turbine in use in New York Harbor.

Figure 4-16: Brake-specific PM emissions over the line-haul duty cycle for a Tier 2 locomotive and the expected reductions in PM emissions due to reduced fuel sulfur levels and application of PM emissions controls.

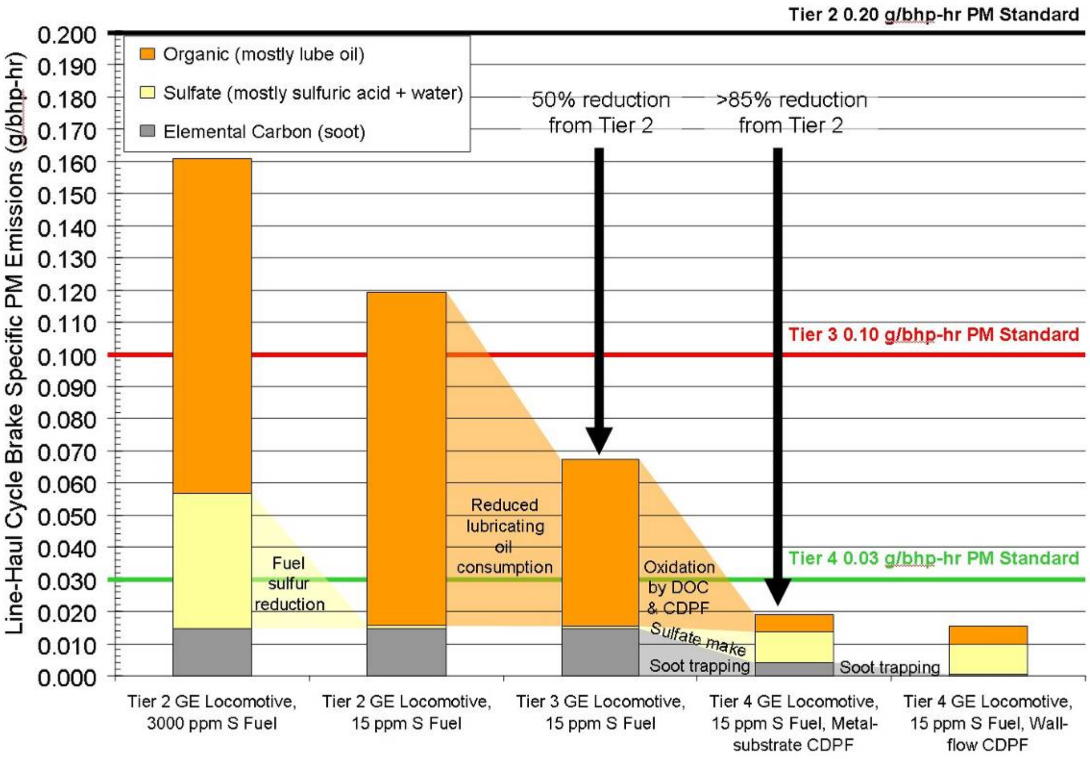


Figure 4-17: Brake-specific PM emissions over the E3 General Marine Duty Cycle for a Tier 2 medium-speed Category 2 diesel engine[E] and the expected reductions in PM emissions due to reduced fuel sulfur levels and application of PM emissions controls.

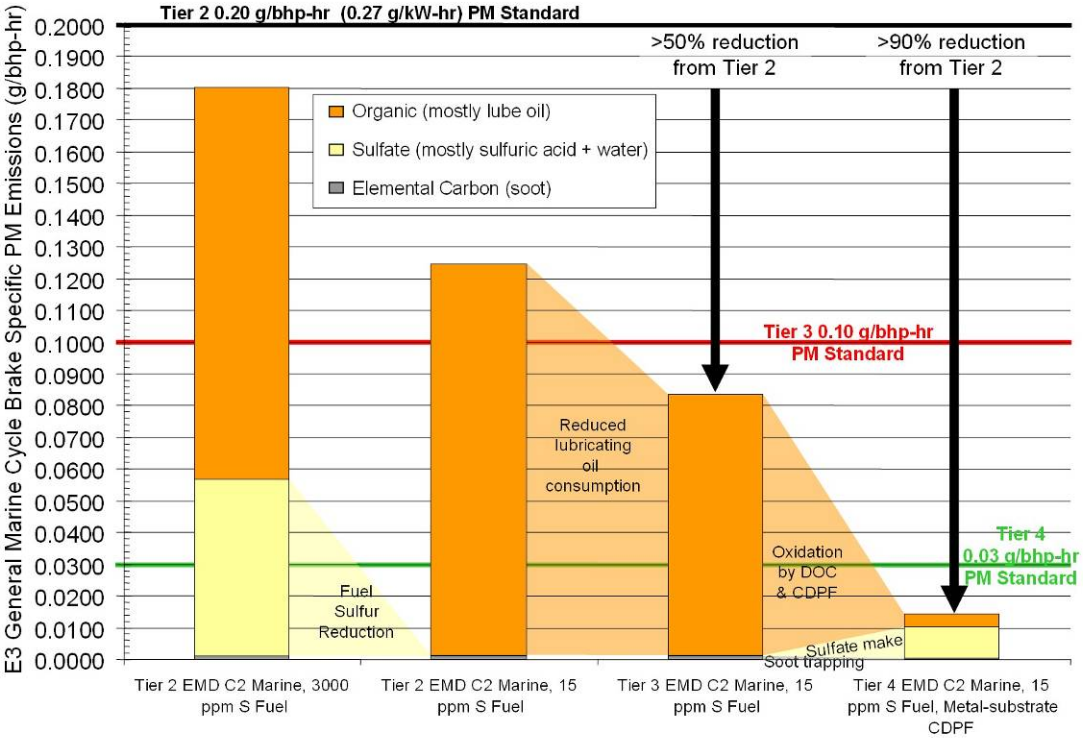
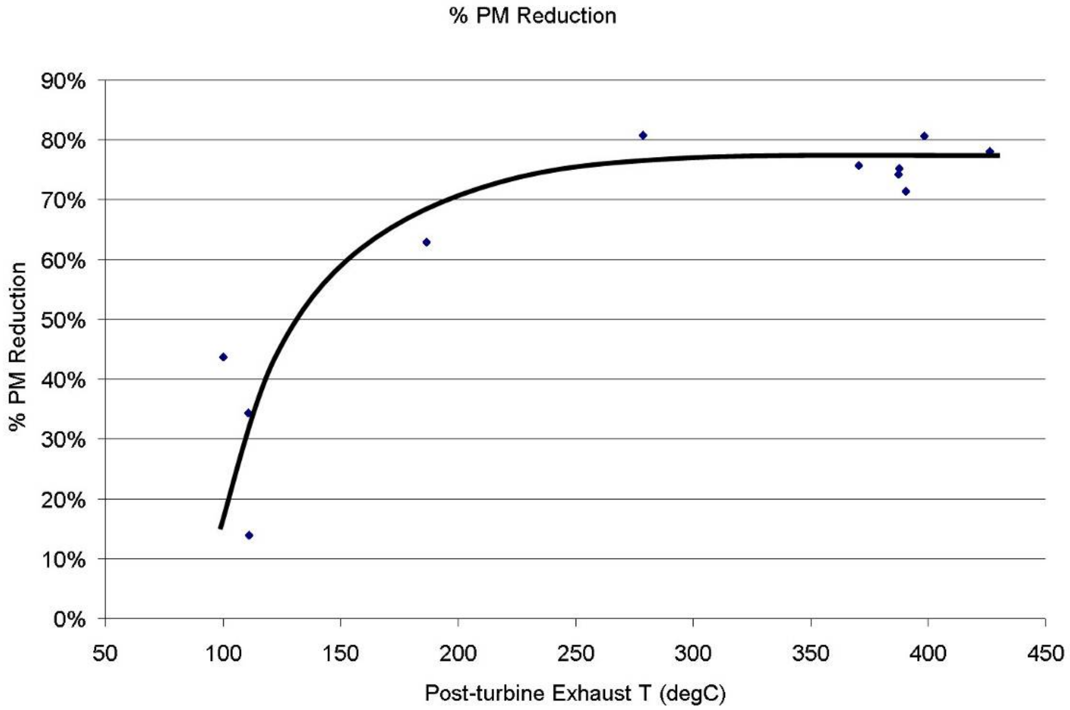


Figure 4-18: Expected PM reduction versus exhaust temperature for a combined DOC and Metal-CDPF system using 15 ppm sulfur fuel when applied to a Tier 3 locomotive. Below 200 °C, PM is dominated by organic carbon emissions, which can only be removed via catalytic oxidation and not by filtration because they are in the gas-phase in the raw exhaust. Thus (organic) PM removal is limited by the kinetically-limited HC oxidation rates over the precious metal catalyst applied to the DOC and the CDPF.



4.3.3 SCR and CDPF Packaging Feasibility

We expect that locomotive and marine manufacturers may need to re-package/re-design the exhaust system, turbocharger, and intake air aftercooling components to accommodate the aftertreatment components. It is acknowledged that the existing overall length, width, and height dimensions of the locomotive are constrained by the existing infrastructure such as tunnel height, but our analysis shows the packaging requirements are such that they can be accommodated within the constraints of a locomotive. For commercial marine vessels, our discussions with marine architects and engineers, along with our review of vessel characteristics, leads us to conclude for engines >600 kW on-board commercial marine vessels, adequate engine room space can be made available to package aftertreatment components. Packaging of these components, and analyzing their mass/placement effect on vessel characteristics, will become part of design process undertaken by naval architecture and marine engineering firms.[45]

To achieve an acceptable balance between SCR performance and exhaust system backpressure, we estimate the volume of the SCR will need to be approximately 2.5 times the engine displacement. This volume includes the volume required for an ammonia-slip-catalyst zone coated to the final 15% of the volume of the SCR monoliths. The SCR volume is determined by sizing the device so that pollutants/reductants have adequate residence time within catalyst to complete the chemical reactions under peak exhaust flow (maximum power) conditions. The term used by the exhaust aftertreatment industry to describe the relationship between exhaust flow rate and catalyst residence time is "space velocity". Space velocity is the ratio of the engine's peak exhaust flow (in volume units-per-hour) to the volume to the aftertreatment device - this ratio is expressed as "inverse hours", or $^{-hr}$. For example, an engine with a displacement of 200 liters (L), 300,000 L/min of exhaust flow, and a 450 L SCR would have a space velocity of $40{,}000^{-hr}$ and a catalyst-to-engine displacement ratio of 2.25:1.[F] Typical space velocities for SCR on existing Euro 5 heavy-duty truck applications range from 60,000 to $80{,}000^{-hr}$.

To achieve acceptable elemental carbon PM capture efficiency, organic carbon PM oxidation efficiency and exhaust system backpressure, the volume of a metal-CDPF will need to be approximately 1.7 times the engine displacement, which would give a maximum space velocity of approximately $60{,}000^{-hr}$. The exhaust-manifold-mounted DOC located upstream of the metal CDPF will need to be approximately 0.8 times the engine displacement with a maximum space velocity of approximately $80{,}000^{-hr}$ in notch 6 (approximately $120{,}000^{hr}$ in notch 8). Typical space velocity for combined DOC/CDPF systems for Euro 4, Euro 5, and U.S. 2007 heavy-duty truck applications range from approximately 60,000 to $80{,}000^{-hr}$.

4.3.4 Stakeholder Concerns Regarding Locomotive NO_x Standard Feasibility

One stakeholder has expressed a number of concerns regarding the feasibility of the proposed 1.3 g/bhp-hr Tier 4 locomotive NO_x standard. The issues raised by the stakeholder can be summarized into three broad areas of concern:

1. Ammonia (urea) dosing
2. Deterioration of SCR catalyst NO_x control
3. Locomotive parity with the marine Tier 4 NO_x standard

4.3.4.1 Ammonia/Urea dosing

The dosing concern specified that variability in urea quality (concentration), urea delivery (dosing), and engine-out NO_x level limits the maximum NO_x reduction potential of the SCR system in order to control ammonia slip to a level <20 ppm. This concern is valid only if urea dosing is controlled in an “open-loop” manner (or operated without consideration of - or inputs from – actual conditions present in the

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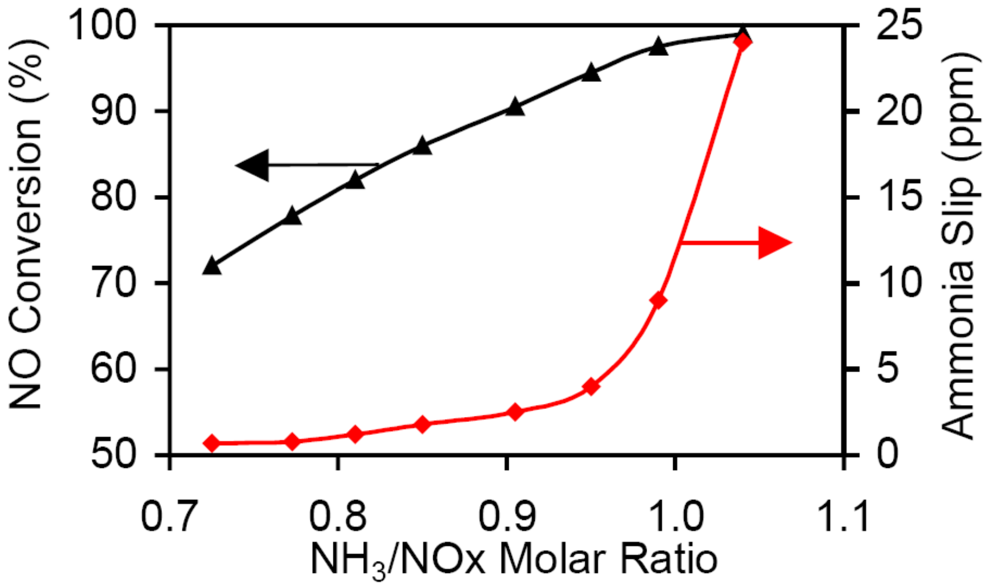
[F] Space Velocity =300,000 L/min * 60 min/hr/450 L, Catalyst-to-Engine Displacement = 450 L/200 L.

exhaust system and within the SCR catalysts.) If the urea dosing is controlled in a "closed-loop" manner, where feedback from NO_x and exhaust gas temperature sensors before/after the SCR catalyst is used to adjust the urea dosing rate, the SCR catalyst can operate at near-peak NO_x conversion efficiency while minimizing NH_3 slip. The use of an NH_3 slip catalyst to clean up any ammonia released from the SCR provides an additional level of robustness to the closed-loop urea dosing system. For example, if exhaust gas and SCR temperature conditions at a particular engine speed/load point allowed for a maximum of 60% NO_x conversion efficiency, it would not be necessary to dose urea at an NH_3-to-NO_x ratio (α) of 1:1 (which would allow at least 40% of the NH_3 to slip) when an α of ~0.6 could achieve nearly the same level of NO_x control while minimizing NH_3 slip.[46] As shown in Figure 4-19, the relationship between dosing ratio and NO_x conversion is linear up to a ratio of ~0.95 (i.e. an α of 0.7 yields a NO_x conversion of 70%, an α of 0.8 yields a NO_x conversion of 80%, and so on). If the dosing ratio is increased beyond 0.95, the additional NH_3 injected will not produce a corresponding increase in NO_x conversion, but will begin to result in NH slip. An effective urea dosing system will operate at this "knee" in curve to maximize NO_x conversion while keeping slip below a designated target value.

Figure 4-19: Effect of dosing ratio on NO_x conversion efficiency and NH3 slip.[46]

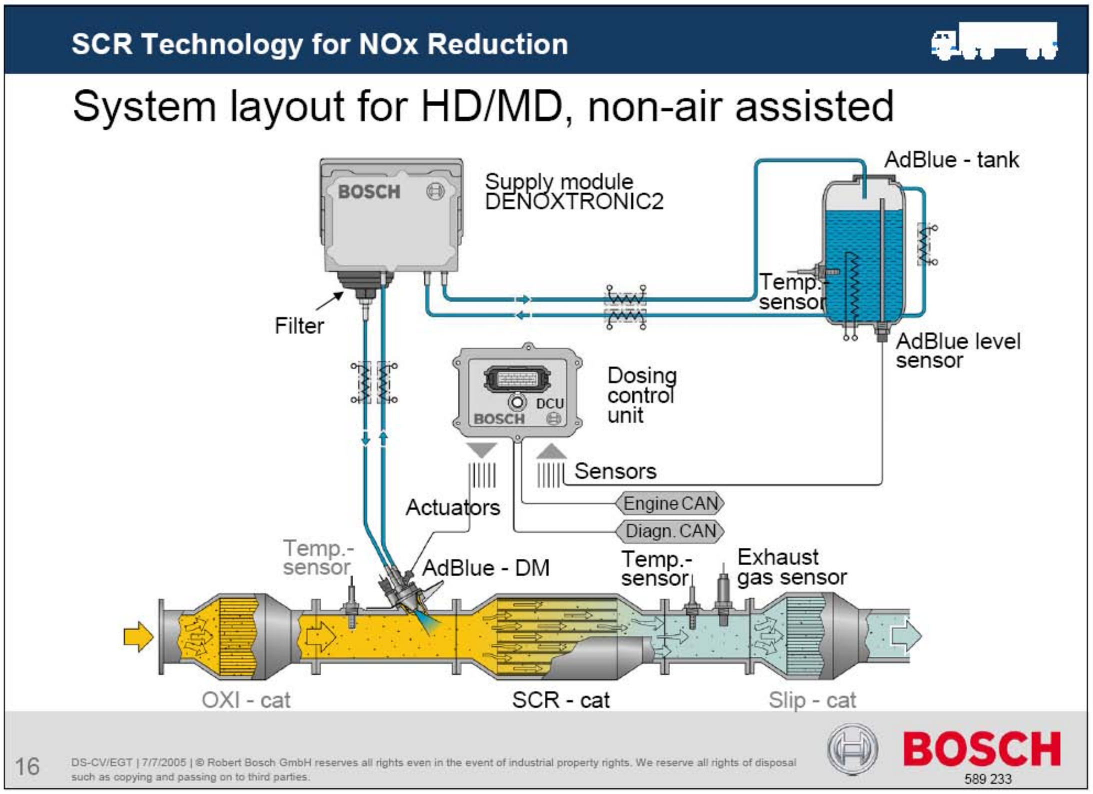


A NO_x sensor before (or upstream of) the SCR can be used as a "feed forward" control input to set the target urea dosing rate and a sensor after (or downstream of) the SCR can be used as "feedback" to fine-tune the dosing rate for optimum NO_x reduction while limiting ammonia slip. In addition, the feedback control provided by a closed-loop urea dosing system also mitigates any variation in concentration of the urea-water solution and engine-out NO_x levels by adjusting the control sytem to compensate by increasing/decreasing the urea dosing rate. The closed-loop system can also adjust to changes in the NO_x conversion efficiency as the

SCR ages – as efficiency drops, the α can adapt downward, preventing excessive ammonia slip.

Closed-loop urea injection systems are already under development for 2010 U.S. heavy-duty highway diesel engines, U.S. and European light-duty diesel vehicles, and Euro V on-highway diesel trucks, and these applications have similar—if not more dynamic—engine operation as compared to locomotive and marine engine operation. Figure 4-20 illustrates a closed-loop urea-SCR control system proposed for onroad diesel applications.[47] Figure 4-21 illustrates a urea-SCR system concept developed by Volkswagen to meet U.S Tier 2, Bin 5 passenger car emission standards.[48]

Figure 4-20: Adapted from "SCR Technology for NO_x Reduction: Series Experience and State of Development".[47]



SCR Technology for NOx Reduction

System layout for HD/MD, non-air assisted

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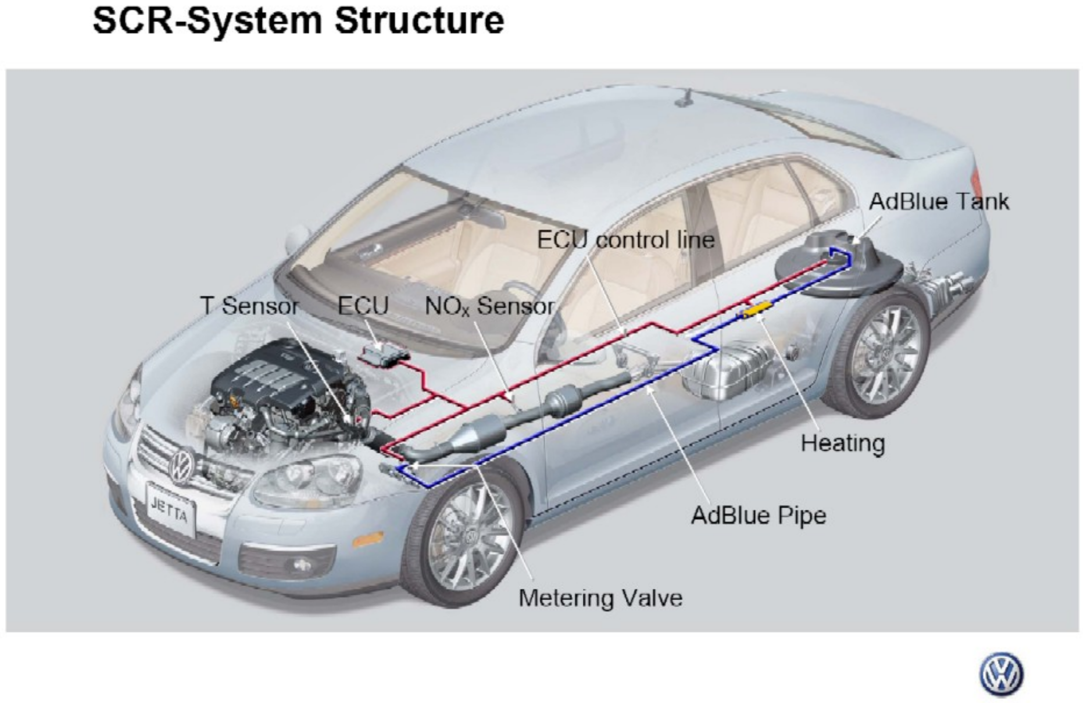
Figure 4-21: Adapted from "LNT or Urea SCR Technology: Which is the right technology for TIER 2 BIN 5 passenger vehicles?"[48]



To ensure accurate urea injection across all engine operating conditions, these systems utilize NO_x sensors to maintain closed-loop feedback control of urea dosing. These NO_x-sensor-based feedback control systems are similar to oxygen-sensor-based systems that are used with three-way catalytic converters on virtually every gasoline vehicle on the road today. The control logic to which the sensors provide input allows for correction of urea dosing to adequately compensate for both production variation and in-use catalyst degradation. We believe these NO_x–sensor-based control systems are directly applicable to locomotive and marine engines.

Ammonia emissions, which are already minimized through the use of closed-loop feedback urea injection, can be all-but-eliminated with an ammonia slip catalyst downstream of the SCR catalyst. Such catalysts are in use today and have been shown to be 95% effective at reducing ammonia emissions. Ammonia slip catalysts that have been developed for Euro V and U.S. 2010 truck applications have reduced selectivity for NO_x formation from ammonia oxidation and can provide additional SCR NO_x conversion via reaction with ammonia within the slip catalyst itself. Catalyst durability is affected by sulfur and other chemicals that can be present in some diesel fuel and lubricating oil. These chemicals have been significantly reduced in other applications by the use of ultra-low sulfur diesel fuel and low-SAPS (sulfated ash, phosphorous, and sulfur) lubricating oil. Locomotive and marine operators already will be using ultra low sulfur diesel fuel by the time urea NO_x SCR systems would be needed, and low SAPS oil can be used in locomotive and marine engines. Thermal and mechanical vibration durability of catalysts has been addressed through the selection of proper materials and the design of support and mounting structures that are capable of withstanding the shock and vibration levels present in locomotive and marine applications. More details on catalyst durability are available in the remainder of this section.

4.3.4.2 Deterioration of NO_x Control with Urea-SCR Systems

A concern has been raised by the stakeholder that the iron-zeolite catalysts (as compared to the vanadium-based catalyst used in trucks in Europe) age rapidly in the presence of real exhaust and when exposed to elevated temperatures. Part of this concern is related to data provided by the stakeholder that had originally been presented by researchers at Ford and General Motors.[32,49] The data was characterized as reaching two conclusions:

1. Fe-zeolite catalysts have NO_x reduction efficiency of only 55% to 65% when NO_x emissions are predominantly NO.[49]

2. The NO to NO_2 conversion efficiency of PGM-based DOC's would rapidly degrade to zero, and thus could not be relied upon to provide any degree of NO to NO_2 oxidation to improve the efficiency of Fe-zeolite SCR catalysts.

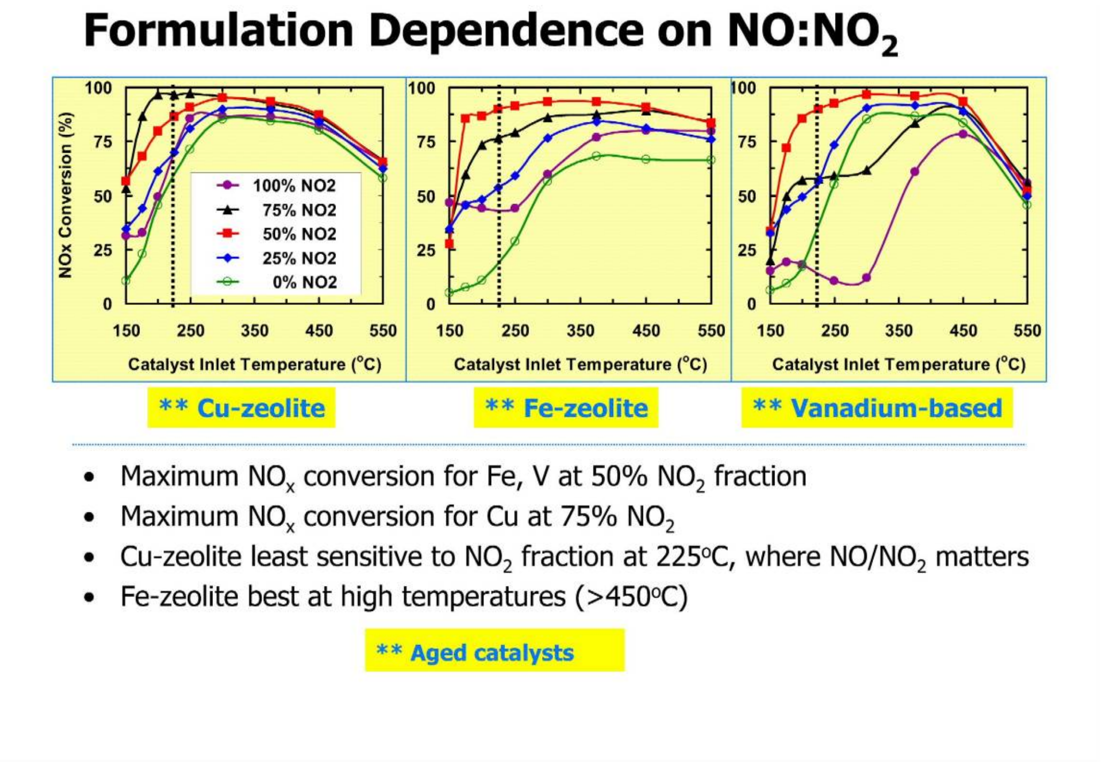
The first point may be the case at for some Fe-zeolite catalysts when operated at catalyst space velocities much higher than those that would be used for locomotive applications (see Figure 4-22). The research cited intentionally undersized the SCR catalyst to accentuate the impact of NO:NO_2 ratio on NO_x conversion When comparing the Fe-Zeolite SCR catalyst example in Figure 4-22 to a similar, aged Fe-Zeolite system at a lower space velocity (Figure 4-23), the NO_x conversion efficiency increases to approximately 80% to 90% over the exhaust temperature range for a line-haul locomotive application for the lower space velocity example with no conversion of NO to NO_2. There are two likely reasons for the differences seen between the results in Figure 4-22 and the results in Figure 4-23:

1. Differences in space velocity between the two SCR catalyst systems.
2. Differences in catalyst formulation and/or the supplier of the SCR catalyst system.

For an appropriately sized locomotive SCR system, >80% NO_x conversion for notches 2 through 8 is still possible even with no oxidation of NO to NO2 upstream of the SCR catalyst. Even when taking into consideration that the catalyst in Figure 4-22 is undersized, it was capable of greater than 75% NO_x conversion with NO_2 as 25% of NO_x and greater than 90% NO_x conversion with NO_2 as 50% of NO_x.

The second point cites NO_2 conversion of only 5-30% at the end of life for a passenger car and then further extrapolates this conversion to near-zero over the life of a locomotive. Upon reviewing the research in question, it was apparent that the 5 to 30% range referred to average conversion over the light-duty FTP cycle, and that the lower end of the range (5%) referred to results achieved when saturating the catalyst with fuel-hydrocarbons. The graph in Figure 4-24 is from the same research cited by the stakeholder, and shows the level of reduced effectiveness for NO to NO2 of the up-front DOC in a compact-SCR system. The four conditions plotted on the curve all represent NO to NO_2 oxidation performance at the same level of thermal aging but with increasing injection of hydrocarbons. The lowest NO_2 oxidation levels reported are for a condition during which the catalyst is completely saturated with hydrocarbons from direct fuel injection into the exhaust. Once fuel injection ceased, NO_2 oxidation returned to the efficiency represented by the upper curve on the chart. The test was meant to show how NO_2 oxidation degrades if the catalyst becomes temporarily hydrocarbon saturated during PM trap forced-regeneration or during cold start, and does not represent aged vs. non-aged DOC results for NO_2 oxidation since all of the conditions shown represent approximately the same thermally-aged condition. Furthermore, in the range of post-turbine exhaust temperatures encountered by 4-stroke line-haul locomotive engines in notches 2 through 8 (approximately 275 °C to 450 °C), NO to NO_2 oxidation ranged from approximately 20% to 50%.

Figure 4-22: A comparison of zeolite-based and vanadium based urea-SCR catalyst formulations at a space velocity of 50,000 hr^{-1} while varying NO_2 as a percentage of NO_x. Adapted from "Evaluation of Supplier Catalyst Formulations for the Selective Catalytic Reduction of NO_x with Ammonia".[49]



Formulation Dependence on NO:NO_2

** Cu-zeolite

** Fe-zeolite

** Vanadium-based

- Maximum NO_x conversion for Fe, V at 50% NO_2 fraction
- Maximum NO_x conversion for Cu at 75% NO_2
- Cu-zeolite least sensitive to NO_2 fraction at 225°C, where NO/NO_2 matters
- Fe-zeolite best at high temperatures (>450°C)

** Aged catalysts

Figure 4-23: NO_x conversion efficiency for an Fe-Zeolite urea-SCR catalyst system while varying NO_2 as a percentage of NO_x.[50] Note that the black line represents the case of NO_x that is 100% NO (0% NO_2).

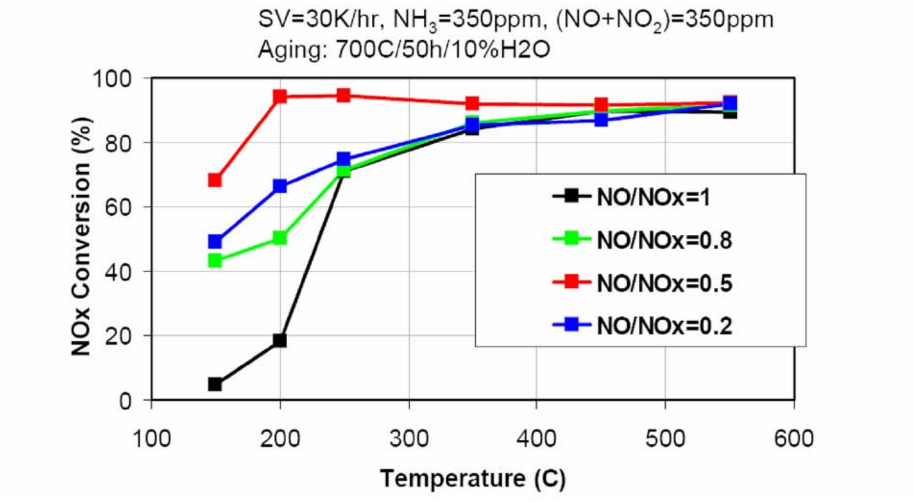


Figure 4-24: Oxidation of NO to NO_2 using a PGM-containing DOC and increasing levels of direct fuel hydrocarbon injection into the exhaust. Exhaust temperatures representative of operation of a 4-stroke line-haul locomotive are marked in red. Adapted from "Urea SCR and DPF System for Tier 2 Diesel Light-Duty Truck".[32]

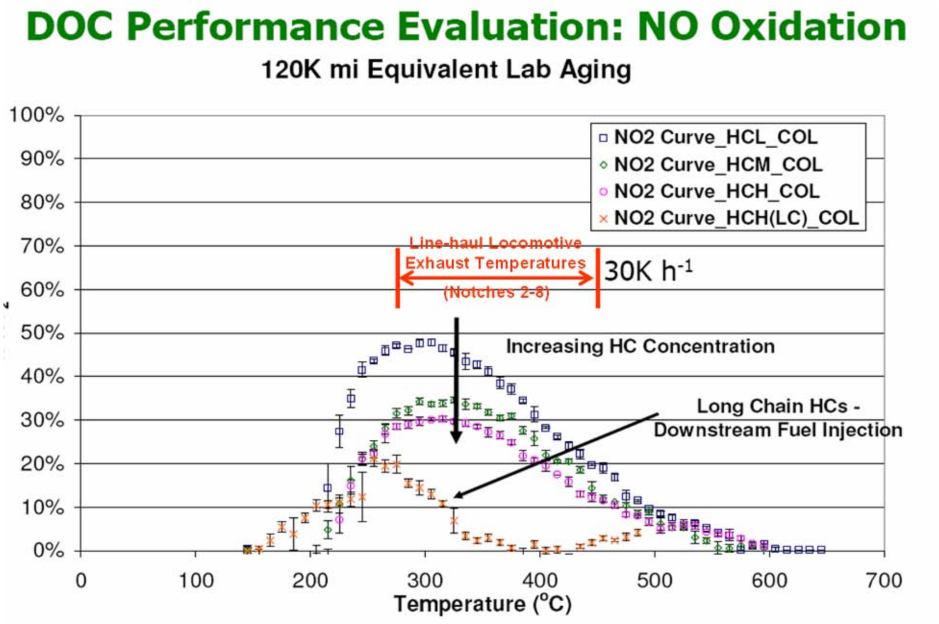
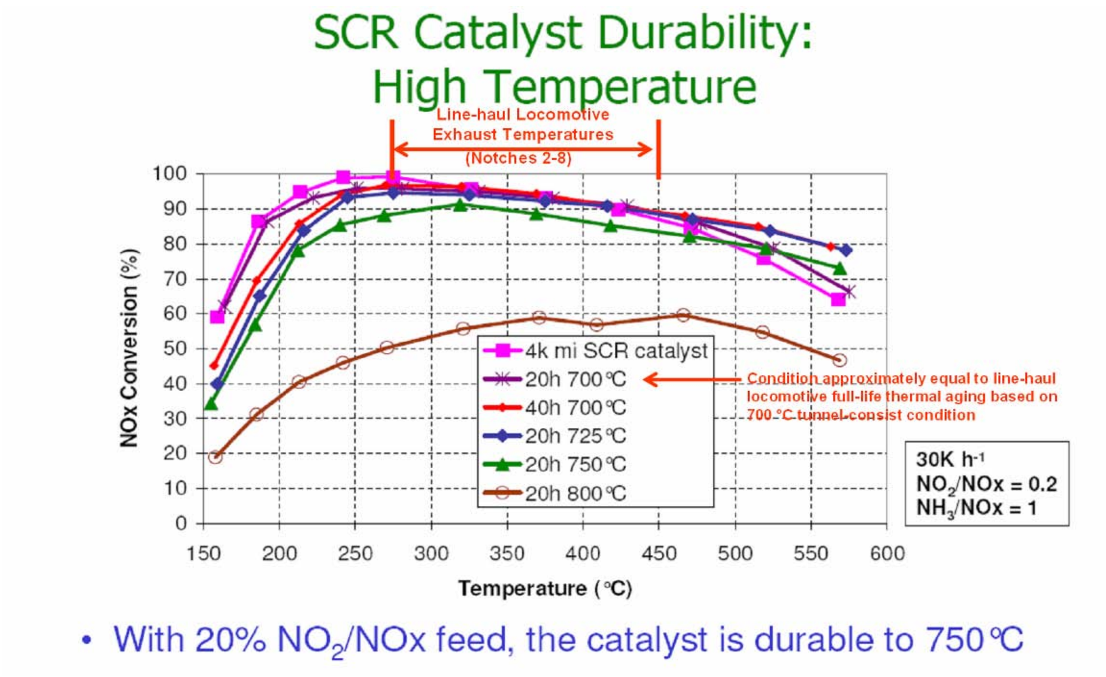


Figure 4-25 shows SCR system performance from the same work by Ford researchers, which shows greater than 90% NO_x control over exhaust temperatures consistent with locomotive operation in notches 2 through 8. The results shown following 20 hours of thermal aging at 700 °C are approximately representative of the maximum thermal aging that would be encountered during the useful life of a locomotive.[G] The results for 40 hours of thermal aging at 700 °C (or roughly double the thermal conditions encountered due to locomotive consist operation in tunnels) still shows nearly identical NO_x performance to the 20 hour results in the range of temperatures representative of locomotive notches 2 through 8 and are generally consistent with the results shown in Figure 4-23 at comparable NO_2 as a percentage of NO_x.

Figure 4-25: NO_x conversion efficiency with 20% conversion of NO to NO_2 for Fe-Zeolite SCR following different thermal aging conditions. The condition of 20 hours at 700 °C is approximately equivalent to full-life thermal aging for a line-haul locomotive taking into account that the highest temperatures encountered will be during tunnel operation as part of a consist. Adapted from "Urea SCR and DPF System for Tier 2 Diesel Light-Duty Truck".[32]



[G] The typical maximum exhaust temperature for a locomotive is 450 °C. During tunnel operation in a consist, this temperature can reach 700 °C. However, not all locomotives operate in tunnels, and only select locomotives will ever experience this type of operation. Discussions with locomotive manufacturers indicate that the typical, yearly accumulated time for units used in tunnel operation 2 hours. If the locomotive life is 10 years, 20-hours will be the maximum time that an SCR will be exposed to elevated exhaust gas temperature conditions.

4.3.4.3 Locomotive Parity with the Marine Tier 4 NO_x Standard

The stakeholder also expressed concern that with everything else being equal, a marine engine capable of achieving the 1.3 g/bhp-hr NO_x when tested to the marine duty cycle would only meet 1.7 g/bhp-hr NO_x when tested to the locomotive duty cycle. This would be due primarily to the way that the respective duty cycles used for emissions testing are conducted and weighted. The E3 Marine Duty Cycle operational points have exhaust temperatures that correspond to relatively high NO_x reduction efficiency with urea-SCR catalyst systems. The line-haul locomotive test cycle includes some operational points with exhaust temperatures that may be too low for high SCR NO_x reduction efficiency (low idle, high idle, dynamic brake and Notch 1). But, all things aren't equal. The locomotive emissions test cycle allows adjustments for reduced idle emissions from the new electronic control systems such as "automated start/stop" that our proposal would require to be used by all manufacturers. The Category 2 marine engines that are comparable to, or larger than, line-haul locomotive engines will meet the same 1.3 Tier 4 NO_x standard with SCR three years sooner. They will also be meeting the Tier 4 NO_x standard from a higher engine-out NO_x emissions baseline since many Category 2 Tier 2 Marine engines are currently meeting a 7.3 g/bhp-hr NO_x standard versus current Tier 2 locomotive standard at 5.5 g/bhp-hr NO_x. Thus the Tier 4 standards actually represent a slightly higher 82% NO_x reduction for Tier 4 marine engines vs. 77% for Tier 4 locomotives. Therefore we believe that the Tier 4 NO_x standards for marine diesel engines are appropriate and represent roughly the same level of emissions stringency.

4.4 Feasibility of Marine NTE Standards

We are proposing certain changes to the marine diesel engine NTE standards based upon our understanding of in-use marine engine operation and based upon the underlying Tier 3 and Tier 4 duty cycle emissions standards that we are proposing. As background, we determine NTE compliance by first applying a multiplier to the corresponding duty-cycle emission standard, and then we compare to that value an emissions result that is recorded when an engine runs within a certain range of engine operation. This range of operation is called an NTE zone. Refer to 40 CFR §94.106 for details on how we currently define this zone and how we currently apply the NTE multipliers within that zone.

Based upon our best information of in-use marine engine operation, we are proposing to broaden certain regions of the marine NTE zones, while narrowing other regions. It should be noted that the first regulation of ours that included NTE standards was the commercial marine diesel regulation, finalized in 1999. After we finalized that regulation, we promulgated other NTE regulations for both heavy-duty on-highway and nonroad diesel engines. We also finalized a regulation that requires heavy-duty on-highway engine manufacturers to conduct field testing to demonstrate in-use compliance with the on-highway NTE standards. Throughout our development of these other regulations, we have learned many details about how best to specify NTE zones and multipliers that help ensure the greatest degree of in-use emissions control, while at the same time help avoid disproportionately stringent requirements for engine operation that has only a minor contribution to an engine's overall impact on the environment. Specifically, we are broadening the NTE zones in order to better control emissions in regions of engine operation where an engine's emissions rates (i.e. grams/hour, tons/day) are greatest; namely at high engine speed and high engine load. This is especially important for controlling emissions from commercial marine engines because they typically operate at steady-state at high-speed and high-load. This also would make our marine NTE zones much more similar to our on-highway and nonroad NTE zones. Additionally, we analyzed different ways to define the marine NTE zones, and we determined a number of ways to improve and simplify the way we define and calculate the borders of these zones. We feel that these improvements would help clarify when an engine is operating within a marine NTE zone. We are also proposing for the first time NTE zones for auxiliary marine engines for both Tier 3 and Tier 4 standards. Because these engines are very similar to constant-speed nonroad engines, we are proposing to adopt the same NTE provisions for auxiliary marine engines as we have already adopted for constant-speed nonroad engines. Note that we currently specify different duty cycles to which a marine engine may be certified, based upon the engine's specific application (e.g., fixed-pitch propeller, controllable-pitch propeller, constant speed, etc.). Correspondingly, we also have a unique NTE zone for each of these duty cycles. These different NTE zones are intended to best reflect an engine's real-world range of operation for that particular application. Refer to the figures in our proposed changes to 40 CFR Part 1042, Appendix III, for illustrations of the changes we are proposing.

We are also proposing changes to the NTE multipliers. We have analyzed how our proposed Tier 3 and Tier 4 emissions standards would affect the stringency of our current marine NTE standards, especially in comparison to the stringency of the underlying duty cycle standards. We recognized that in certain sub-regions of our proposed NTE zones, slightly higher multipliers would be necessary because of the way that our more stringent proposed Tier 3 and Tier 4 emissions standards would affect the stringency of the NTE standards. For comparison, our current marine NTE standards contain multipliers that range in magnitude from 1.2 to 1.5 times the corresponding duty cycle standard. In the changes we are proposing, the new multipliers would range from 1.2 to 1.9 times the standard. Refer to the figures in our proposed changes to 40 CFR Part 1042, Appendix III, for illustrations of the changes we are proposing.

We are also proposing to adopt other NTE provisions for marine engines that are similar to our existing heavy-duty on-highway and nonroad diesel NTE standards. We are proposing these particular changes to account for the implementation of catalytic exhaust treatment devices on marine engines and to account for when a marine engine rarely operates within a limited region of the NTE zone.

Aftertreatment systems generally utilize metallic catalysts, which become highly efficient at treating emissions above a minimum exhaust temperature. For the most commonly used metallic catalysts, this minimum temperature occurs in the range of about (150 to 250) °C. In our recent on-highway and nonroad regulations, we identified NO_x adsorber-based aftertreatment technology as the most likely type of technology for on-highway and nonroad NO_x aftertreatment. This NO_x adsorber technology utilizes barium carbonate metals that become active and efficient at temperatures at or above 250 °C. Also, in our on-highway and nonroad rulemakings we identified platinum and platinum/palladium diesel oxidation catalyst technology for hydrocarbon emissions control. This technology also becomes active and efficient at temperatures at or above 250 °C. Therefore, in our on-highway and nonroad rulemakings for NO_x and hydrocarbons emissions, we set a lower exhaust temperature NTE limit of 250 °C, as measured at the outlet of the last aftertreatment device. We only considered engine operation at or above this temperature as potential NTE operation.

For marine applications we have identified similar hydrocarbon aftertreatment emissions control technology (i.e. diesel oxidation catalyst or DOC). However, we have identified different aftertreatment technology for NO_x control, as compared to our on-highway and nonroad rulemakings. Specifically, we have identified selective catalytic reduction (SCR) NO_x control technology, which we discussed in detail earlier in this chapter. We believe that the performance of this different technology needs to be considered in setting the proper exhaust temperature limits for the marine NTE standards. That is why we are proposing that the NTE standards for NO_x would apply at exhaust temperatures equal to or greater than 150 °C, as measured within 12 inches of the last NO_x aftertreatment device's outlet. For hydrocarbon aftertreatment systems, this minimum temperature limit would be 250 °C, which is the same as our on-highway and nonroad NTE standards.

4.5 Conclusions

Even though our proposal covers a wide range of engines and thus requires the implementation of a range of emissions controls technologies, we believe we have identified a range of technologically feasible emissions control technologies that likely would be used to meet our proposed standards. Some of these technologies are incremental improvements to existing engine components, and many of these improved components have already been applied to similar engines. The other technologies we identified involve catalytic exhaust treatment systems. For these technologies we carefully examined the catalyst technology, its applicability to locomotive and marine engine packaging constraints, its durability with respect to the lifetime of today’s locomotive and marine engines, and its impact on the infrastructure of the rail and marine industries. From our analysis, based upon numerous data from automotive, truck, locomotive, and marine industries, we conclude that incremental improvements to engine components and the implementation of catalytic PM and NO_x exhaust treatment technology are technologically feasible for locomotive and marine applications, and thus may be used to meet our proposed emissions standards.

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CHAPTER 5: Engineering Cost Estimates

This chapter presents the engine and equipment engineering costs we have estimated for meeting the new engine emissions standards.[a] Section 5.1 includes a brief outline of the methodology used to estimate the engine and equipment costs. Sections 5.2 and 5.3 present the projected costs of the individual technologies we expect manufacturers to use to comply with the new emissions standards, along with a discussion of fixed costs such as research, tooling, certification, and equipment/vessel redesign. Section 5.4 presents our estimate of changes in the operating costs that would result from the proposed program and section 5.5 presents costs associated with the locomotive remanufacturing program. Section 5.6 summarizes these costs and presents the total program costs. Section 5.7 presents costs associated with a possible marine remanufacturing program, although this program is not being proposed.

To maintain consistency in the way our emission reductions, costs, and cost-effectiveness estimates are calculated, our cost methodology relies on the same projections of new locomotive and marine engine growth as those used in our emissions inventory projections. Our emission inventory analyses for marine engines and for locomotives include estimates of future engine populations that are consistent with the future engine sales used in this cost analysis.

Note that the costs here do not reflect changes to the fuel used to power locomotive and marine engines. Our Nonroad Tier 4 rule controlled the sulfur level in all nonroad fuel, including that used in locomotives and marine engines.[b] The sulfur level in the fuel is a critical element of the proposed locomotive and marine program. However, since the costs of controlling locomotive and marine fuel sulfur have been considered in our Nonroad Tier 4 rule, they are not considered here. This analysis considers only those costs associated with the proposed locomotive and marine program.

Additionally, the costs presented here do not reflect any savings that are expected to occur because of the engine ABT program and the various flexibilities included in the program. These program features have the potential to provide savings for both engine and locomotive/vessel manufacturers. While we fully expect companies to use them to reduce compliance costs, we do not factor them into the cost analysis because they are voluntary programs. This analysis of compliance costs

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[a] We use the term “engineering costs” to differentiate from “social costs.” Social costs are discussed in Chapter 7 of this draft RIA. For simplicity, the terms “cost” and “costs” throughout the discussion in this Chapter 5 should be taken as referring to “engineering costs.”

[b] See the Regulatory Impact Analysis for the Nonroad Tier 4 final rule, EPA420-R-04-007, May 2004.

relates to regulatory requirements that are part of the proposed rule for Tiers 3 and 4 emissions standards for locomotive and marine engines. Unless noted otherwise, all costs are in 2005 dollars ($2005).

5.1 Methodology for Estimating Engine and Equipment Engineering Costs

This analysis makes several simplifying assumptions regarding how manufacturers will comply with the new emission standards. First, for each tier of emissions standards within a given category of engine, we assume a single technology recipe. For example, all Tier 4 engines in the locomotive category are estimated to be fitted with a selective catalytic reduction (SCR) system, a diesel particulate filter (DPF), and a diesel oxidation catalyst (DOC). However, we expect that each manufacturer will evaluate all possible technology avenues to determine how to best balance costs while ensuring compliance. As noted, for developing cost estimates, we have assumed that the industry does not make use of the averaging, banking, and trading program, even though this program offers industry the opportunity for significant cost reductions. Given these simplifying assumptions, we believe the projections presented here overestimate the costs associated with different compliance approaches manufacturers may ultimately take.

Through our background work for this locomotive and marine rule, our past locomotive and marine rules, and our recent highway and nonroad diesel rules, we have sought input from a large section of the regulated community regarding the future costs of applying the emission control technologies expected for diesel engines within the context of this proposed program. Under contract with EPA, ICF International (formerly 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 to estimate costs for “traditional” engine technologies such as EGR, fuel-injection systems, and for marinizing systems for use in a marine environment.[1,2]

Costs for exhaust emission control devices (e.g., catalyzed DPFs, SCR systems, and DOCs) were estimated using the methodology used in our 2007 heavy-duty highway rulemaking. In that rulemaking effort, surveys were provided to nine engine manufacturers seeking information relevant to estimating 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 anticipated for meeting the 2007 heavy-duty highway standards. We then built upon these costs based on input from members of the Manufacturers of Emission Controls Association (MECA). We also used this approach as the basis for estimating costs for our recent nonroad tier 4 (NRT4) rulemaking effort. Because the anticipated emission control technologies for use on locomotive and marine engines are the same as, or similar to, those expected for highway and nonroad engines, and because the suppliers of the technologies are the same for of these engines, we have used that analysis as the basis for estimating the costs of these technologies in this rulemaking.[3]

Costs of control include variable costs (for new hardware, its assembly, and associated markups) and fixed costs (for tooling, research, redesign efforts, and certification). For technologies sold by a supplier to the engine manufacturers, costs are either estimated based on 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 on estimates from suppliers on expected total costs to the manufacturers (inclusive of markups).[4] 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 carrying cost—estimated to be four percent of the direct costs—accounts for the capital cost of the extra inventory and the incremental costs of insurance, handling, and storage. The dealer carrying cost—estimated to be three percent of their direct costs—accounts for the cost of capital tied up in extra inventory. We adopted this same approach to markups in the 2007 heavy-duty highway rule and the NRT4 rule, based on industry input.[5]

We have also identified various factors that cause costs to decrease over time, making it appropriate to distinguish between near-term and long-term costs. Research on 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. This analysis incorporates the effects of this learning curve as described in Section 5.2.2.[6]

Fixed costs for engine research are estimated to be incurred over the five-year period preceding introduction of the engine. Fixed costs for engine tooling and certification are estimated to be incurred one year ahead of initial production. Fixed costs for equipment redesign are also estimated to be incurred one year ahead of production. We have also included lifetime operating costs where applicable. These include costs associated with fuel consumption impacts and urea use, and increased maintenance demands resulting from the addition of new emission-control hardware. We have also included incremental costs associated with an increase in remanufacturing costs due to the inclusion of additional hardware as part of the remanufactured engine.

A simplified overview of the methodology used to estimate engine and equipment costs is as follows:

- For engine research, we have estimated the total dollars that we believe each engine manufacturer will spend on research to make DPF and SCR systems work together. We refer to such efforts as corporate research. Also for engine research, we have estimated the dollars spent to tailor the corporate research to each individual engine line in the manufacturer's product mix. We refer to such efforts as engine-line research.

- For engine-related tooling costs, we have estimated the dollars that we believe each engine manufacturer will spend on tooling for each of its engine lines. This amount varies depending on whether the manufacturer makes only locomotive and/or marine engines or also makes highway and/or nonroad engines. This amount also varies depending on the emissions standards to which the engine line is certified (i.e., Tier 3 or 4).

- For engine variable costs (i.e., emission-control hardware), we use a three-step approach:

    - First, we estimate the cost per piece of technology/hardware. As described in detail in Section 5.2.2, emission-control hardware costs tend to be directly related to engine characteristics—for example, most emission control devices are sized according to engine displacement so costs vary by displacement. Because of this relationship, we are able to determine a variable cost equation as a function of engine displacement.

    - Second, we determine a sales weighted baseline technology package using a database from Power Systems Research of all locomotive and marine engines sold in the United States.[7] That database lists engine characteristics for every one of over 40,000 locomotive and marine engines sold in the United States in any given year. Using the baseline engine characteristics of each engine, the projected technology package for that engine, and the variable cost equations described in Section 5.2.2, we calculate a variable cost for the sales weighted average engine in each of several different engine categories.

    - Third, this weighted average variable cost is multiplied by the appropriate projected sales in each year after the new standards take effect to give total annual costs for each engine category. The sum total of the annual costs for all engines gives the fleetwide variable costs per year.

- Equipment related costs—i.e., marine vessels or locomotives—are generated using the same methodology to estimate the fixed costs for equipment redesign efforts and the variable costs for new brackets, bolts, and sheet metal that we expect will be required.

This chapter addresses a number of costs including: Engine costs – fixed costs then variable costs; equipment costs – fixed costs then variable costs; and, operating costs – urea, maintenance, and fuel consumption impacts; and, remanufacturing program costs. A summation of these costs is presented in Section 5.6. Variable cost estimates for both engines and equipment represent an expected incremental cost of the engine or piece of equipment in the model year of introduction. Variable costs per engine decrease in subsequent years as a result of several factors, as described below, although these factors do not apply to equipment variable costs. All costs are presented in 2005 dollars.

5.2 Engine-Related Engineering Costs for New Engines

5.2.1 New Engine Fixed Engineering Costs

Engine fixed costs consist of research, tooling, and certification. For these costs, we have made a couple of simplifying assumptions with regard to the timing of marine-related expenditures due to the complexity of the roll out of the marine engine standards. We have estimated that, in general, the marine engine fixed costs would be incurred during the years prior to 2012 (for Tier 3 related costs) and 2016 (for Tier 4 related costs). While this approach impacts the timing of marine-related expenditures and, thus, the annual costs during the early years of implementation, it has no impact on the total costs we would estimate in association with the proposed standards. However, while having no impact on the total costs we estimate would be incurred, this approach does have a very minor impact on the net present value of costs since some early costs (e.g., those for <75 kW Tier 3 engines and >3,700 kW Tier 4 NO_x) are effectively pushed back a couple of years. We believe that the approach taken makes it easier to follow the presentation of costs while having no impact on the results of the analysis.

5.2.1.1 Engine and Emission Control Device Research

As noted, we estimate costs for two types of engine research—corporate research, or that research conducted by manufacturers using test engines to learn how NO_x and PM control technologies work and how they work together in a system; and, engine line research, or that research done to tailor the corporate knowledge to each particular engine line. For the Tier 3 standards, we are estimating no corporate research since the technologies expected for Tier 3 are “existing” technologies and are well understood. However, we have estimated engine-line research associated with Tier 3 since those technologies will still need to be tailored to each engine-line. For Tier 4, we have estimated considerable corporate research since the technologies expected for Tier 4 are still considered “new” technologies in the diesel engine market. We have also estimated more engine-line research for Tier 4 so that the corporate research may be tailored to each engine.

We start this discussion with the more global corporate research. The technologies described in Chapter 4 represent those technologies we believe will be used to comply with the proposed emission standards. These technologies are also part of an ongoing research and development effort geared toward compliance with the 2007 heavy-duty highway and the nonroad Tier 4 standards and, to some extent, the current and future light-duty diesel vehicle standards in the US and Europe. Those engine manufacturers making research expenditures toward compliance with either highway or nonroad emission standards will have to undertake some research effort to transfer emission-control technologies to engines they wish to sell into the locomotive and/or marine markets. These research efforts will allow engine manufacturers to develop and optimize these new technologies for maximum emission control effectiveness, while continuing to design engines with good performance, durability, and fuel efficiency characteristics. However, many engine manufacturers are not part of the ongoing research effort toward compliance with highway and/or nonroad emission standards because they do not sell engines into the highway or nonroad markets. These manufacturers–i.e., the locomotive/marine-only manufacturers–are expected to learn from the research work that has already occurred and will continue through the coming years through their contact with highway and nonroad manufacturers, emission-control device manufacturers, and the independent engine research laboratories conducting relevant research. Despite these opportunities for learning, we expect the research expenditures for these loco/marine-only manufacturers to be higher than for those manufacturers already conducting research in response to the highway and nonroad rules.

We are projecting that SCR systems and DPFs will be the most likely technologies used to meet the new Tier 4 emission standards. Because these technologies are being researched for implementation in the highway and nonroad markets well before the locomotive and marine emission standards take effect, and because engine manufacturers will have had several years complying with the highway and nonroad standards, we believe that the technologies used to comply with the locomotive and marine Tier 4 standards will have undergone significant development before reaching locomotive and marine production. This ongoing research will likely 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 today, given the current state of development. Second, we anticipate that the continuing efforts to improve the emission-control technologies will include innovations that allow lower-cost production. And finally, we believe manufacturers will 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 manufacturers will introduce a combination of primary technology upgrades to meet the new emission standards. Achieving very low NO_x emissions requires basic research on NO_x emission-control technologies and improvements in engine management. Manufacturers are expected to address this challenge by optimizing the engine and exhaust emission-control system to realize the best overall performance. This will entail optimizing the engine and emission control system for both emissions and fuel economy performance in light of the presence of the new exhaust emission control devices and their ability to control pollutants previously controlled only via in-cylinder means or with exhaust gas recirculation. The NO_x control technology in particular is expected to benefit from re-optimization of the engine management system to better match the NO_x catalyst's performance characteristics. The majority of the dollars we have estimated for corporate engine research is expected to be spent on developing this synergy between the engine and NO_x exhaust emission-control systems. Therefore, for engines where we project use of exhaust aftertreatment devices, we have attributed two-thirds of the research expenditures to NO_x+NMHC control, and one-third to PM control. This approach is consistent with that taken in our 2007 heavy-duty highway and NRT4 rules.

To estimate corporate research costs, we begin with our 2007 heavy-duty highway rule. In that rule, we estimated that each engine manufacturer would expend $35 million for corporate research toward successfully implementing diesel particulate filters (DPF) and NO_x control catalysts. For this locomotive/marine analysis, we express all monetary values in 2005 dollars which means our starting point equates to just under $39 million.[8] For their locomotive/marine research efforts, engine manufacturers that also sell into the highway and/or nonroad markets will incur some level of research expense but not at the level incurred for the highway rule. In many cases, the engines used by highway/nonroad manufacturers in marine products are based on the same engine platform as those engines used in their highway/nonroad products. This is also true for locomotive switchers. However, power and torque characteristics are often different, so manufacturers will need to expend some effort to accommodate those differences. For these manufacturers, we assume that they will incur an average corporate research expense of roughly $4 million. This $4 million expense allows for the transfer of learning from highway/nonroad research to their locomotive/marine engines. For reasons noted above, two-thirds of this money is attributed to NO_x+NMHC control and one-third to PM control.

For those engine manufacturers that sell engines only into the locomotive and/or marine markets, and where those engines will be meeting the proposed Tier 4 standards, we believe they will incur a corporate research expense approaching that incurred by highway manufacturers for the 2007 highway rule although not quite at the same level. These manufacturers will be able to learn from the research efforts already underway for both the 2007 highway and nonroad Tier 4 rules (66 FR 5002 and 69 FR 38958, respectively), and for the Tier 2 light-duty highway rule (65 FR 6698) and analogous rules in Europe. This learning may come from seminars, conferences, technical publications regarding diesel engine technology (e.g., Society of Automotive Engineers technical papers), and contact with highway manufacturers, emission-control device manufacturers, and the independent engine research laboratories conducting relevant research. In the NRT4 rule, we estimated that this learning would result in nonroad-only manufacturers incurring 70 percent of the expenditures as highway manufacturers for the 2007 highway rule. Similarly, we would expect that locomotive/marine-only manufacturers would incur 70 percent of the expenditures incurred by nonroad-only manufacturers for the NRT4 rule. Therefore, we have assumed that locomotive/marine-only manufacturers will incur 49 percent of that spent by highway manufacturers in their highway efforts. This lower number—roughly $19 million versus $39 million in the highway rule—reflects the transfer of knowledge to locomotive/marine-only manufacturers from the many stakeholders in the diesel industry. Two-thirds of this corporate research is attributed to NO_x+NMHC control and one-third to PM control.

The $4 million and $19 million estimates represent our estimate of the average corporate research expenditures for engine manufacturers. Each manufacturer may incur more or less than these average figures.

These corporate research estimates are outlined in Table 5-1.

Table 5-1 Estimated Corporate Research Expenditures by Type of Engine Manufacturer Totals per Manufacturer over Five Years ($Million)

	Manufacturer sells only Tier 3 engines	Manufacturer sells Tier 4 engines
Manufacturer sells into highway and/or nonroad markets	$0	$4
Manufacturer sells only into locomotive and/or marine markets	$0	$19
% allocated to PM	n/a	33%
% allocated to NO_X+NMHC	n/a	67%

Note: Since we expect that the majority of the dollars we have estimated for corporate engine research would be spent on developing the synergy between the engine and NO_X exhaust emission-control systems, we have attributed two-thirds of the corporate research expenditures to NO_X+NMHC control and one-third to PM control.

The PSR database shows that there were 47 engine manufacturers that sold engines into the locomotive and marine markets in 2002. Of these 47, 12 sold engines into the market segments proposed to meet the Tier 4 standards (i.e., proposed to need exhaust aftertreatment devices and, therefore, need to conduct this research). Of those 12, three sold exclusively into the locomotive and/or marine markets, while the other nine sold engines into the highway and/or nonroad markets in addition to the locomotive and/or marine markets. As a result, we estimate that three manufacturers will need to spend the full $19 million conducting research and nine will spend $4 million, for a total corporate research expenditure of just over $92 million.

Further, six of these 12 manufacturers sold into both the locomotive and marine markets and, therefore, will spend a portion of their corporate research dollars during the five years prior to 2015 (for DPF research to support locomotive engines), a portion during the five years prior to 2016 (for SCR and DPF research to support marine engines) and the remaining portion during the five years prior to 2017 (for SCR research to support locomotive engines). Of the six remaining manufacturers, five sold only into the marine market so will spend their dollars during the five years prior to 2016 (for SCR and DPF research to support marine engines). The remaining manufacturer sold only into the locomotive market and will spend a portion of its corporate research dollars during the five years prior to 2015 (for DPF research) and the remaining portion during the five years prior to 2017 (for SCR research). Further allocation of corporate research into marine C1, marine C2, locomotive switcher, and locomotive line-haul segments based on the segments into which each manufacturer sold in 2002 results in the total corporate research expenditures by market segment shown in Table 5-2.[c] We then spread these costs over the five years in advance of the applicable standards to get the annual costs shown in Table 5-3.

Table 5-2 Estimated Corporate Research Expenditures Allocated by Market Segment ($Million)

Market Segment	Total Corporate Research Expenditure	PM	NO_x+NMHC
Locomotive Switcher/Passenger	$ 10.4	$ 3.4	$ 7.0
Locomotive Line-Haul	$ 19.1	$ 6.3	$ 12.8
Marine C1	$ 37.3	$ 12.3	$ 25.0
Marine C2	$ 25.6	$ 8.4	$ 17.1
Total Industry Expenditure	$ 92.3	$ 30.5	$ 61.8

Notes: Since we expect that the majority of the dollars we have estimated for corporate engine research would be spent on developing the synergy between the engine and NO_x exhaust emission-control systems, we have attributed two-thirds of the corporate research expenditures to NO_x+NMHC control and one-third to PM control. Marine C1 includes recreational marine $\geq$ 2000 kW.

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[c] Note that, throughout this discussion of costs, recreational marine engines over 2000 kW are included in the C1 marine category unless otherwise noted. As such, when referring to the recreational marine category, we mean recreational marine engines less than 2000 kW unless otherwise noted.

Table 5-3 Estimated Corporate Research Expenditures by Year ($Millions)

Calendar Year	Locomotive Switchers			Locomotive Line-Haul			Marine C1			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2008	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2009	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2010	$0.7	$ -	$0.7	$1.3	$ -	$1.3	$ -	$ -	$ -	$ -	$ -	$ -	$1.9	$1.9	$ -
2011	$0.7	$ -	$0.7	$1.3	$ -	$1.3	$2.5	$5.0	$7.5	$1.7	$3.4	$5.1	$14.5	$6.1	$8.4
2012	$0.7	$1.4	$2.1	$1.3	$2.6	$3.8	$2.5	$5.0	$7.5	$1.7	$3.4	$5.1	$18.5	$6.1	$12.4
2013	$0.7	$1.4	$2.1	$1.3	$2.6	$3.8	$2.5	$5.0	$7.5	$1.7	$3.4	$5.1	$18.5	$6.1	$12.4
2014	$0.7	$1.4	$2.1	$1.3	$2.6	$3.8	$2.5	$5.0	$7.5	$1.7	$3.4	$5.1	$18.5	$6.1	$12.4
2015	$ -	$1.4	$1.4	$ -	$2.6	$2.6	$2.5	$5.0	$7.5	$1.7	$3.4	$5.1	$16.5	$4.1	$12.4
2016	$ -	$1.4	$1.4	$ -	$2.6	$2.6	$ -	$ -	$ -	$ -	$ -	$ -	$3.9	$ -	$3.9
2017	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2018	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$3.4	$7.0	$10.4	$6.3	$12.8	$19.1	$12.3	$25.0	$37.3	$8.4	$17.1	$25.6	$92.3	$30.5	$61.8
NPV at 7%	$2.1	$3.8	$5.9	$3.9	$7.0	$10.9	$7.2	$14.6	$21.8	$4.9	$10.0	$15.0	$53.6	$18.2	$35.4
NPV at 3%	$2.8	$5.3	$8.1	$5.1	$9.8	$14.9	$9.7	$19.7	$29.4	$6.7	$13.5	$20.2	$72.7	$24.3	$48.4

As shown in Table 5-3, the net present value of the corporate research is estimated at $73 million using a three percent discount rate, and $54 million using a seven percent discount rate.[d] We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-4.

Table 5-4 Estimated Corporate Research per Engine

	Estimated Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 8.1	3,212	$ 2,530
Locomotive Line Haul	$ 14.9	19,258	$ 780
Marine C1 >600 kW	$ 29.4	25,597	$ 1,150
Marine C2	$ 20.2	6,647	$ 3,040
Total	$ 72.7	54,715	$ 1,330

Note: Marine C1 >600 kW includes recreational marine ≥ 2000 kW. Net present values of sales are calculated using zero as the sales figure for 2006.

For engine line research—those engine research efforts done to tailor the corporate research to each particular engine line—we have first determined the number of engine lines by considering that, 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-, or eight-cylinder engine may be produced from the same basic engine design. While these engines have different total displacement, they each 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 one engine line. Doing this, we found there to be 88 engine lines that will need Tier 3 engine line research and 31 engine lines that will need Tier 4 engine line research. Of the 88 Tier 3 engine lines, eight are locomotive switcher lines, two are locomotive line haul lines, 13 are C2 marine lines, and 65 are other marine lines which, due to their size, generally span at least two of the three categories of C1 marine, recreational, and small marine. For these 65 marine lines, we have weighted each manufacturer's estimated engine line research costs according to total engine lines sold into each of these three categories

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[d] Throughout Chapter 5 of this draft RIA, net present value (NPV) calculations are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of engineering costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

by the particular manufacturer. Of the 31 Tier 4 engine lines, four engine lines had sales in both the locomotive and the marine markets, so we have split evenly the engine line research between the appropriate segments; two of these four were marine-C1/locomotive-switcher engine lines, while the other two were marine-C2/locomotive-line haul engine lines.

Consistent with our NRT4 rule, for those engine lines adding aftertreatment devices (i.e., the Tier 4 engine lines) we have estimated the engine line research at \$3.2 million per line for those engines under 600 kW and \$6.5 million per line for engines over 600 kW range. For engine line research associated with the Tier 3 standards, we have estimated the expenditure per engine line at \$1.6 million. This value is lower than the amount estimated for Tier 4 since the Tier 3 effort should amount to recalibration work which is less costly than the work expected for Tier 4 engine lines. The estimated engine line research expenditures by type of engine manufacturer are shown in Table 5-5 and by market segment for Tier 3 in Table 5-6 and for Tier 4 in Table 5-7.

Table 5-5 Estimated Engine Line Research Expenditures by Type of Engine Manufacturer Totals per Engine Line for Tiers 3 & 4 ($Million)

	Tier 3 engine line	Tier 4 engine line <600 kW	Tier 4 engine line >600 kW
Manufacturer sells into highway and/or nonroad markets	\$ 1.6	\$ 3.2	\$ 6.5
Manufacturer sells only into locomotive and/or marine markets	\$ 1.6	\$ 3.2	\$ 6.5
% allocated to PM	33%	33%	33%
% allocated to NO_x+NMHC	67%	67%	67%

Note: Since we expect that the majority of the dollars we have estimated for engine line research would be spent on developing the synergy between the engine and NO_x exhaust emission-control systems, we have attributed two-thirds of the engine line research expenditures to NO_x+NMHC control and one-third to PM control.

Table 5-6 Tier 3 Engine Line Research Expenditures by Market Segment ($Million)

Segment	Engine Lines <600 kW	Engine Lines >600 kW	Tier 3 $/line	Total
Small Marine	65		$ 1.6	$ 104
Recreational Marine				
Marine C1				
Marine C2	0	13	$ 1.6	$ 20.8
Locomotive Switcher/Passenger	6*	2	$ 1.6	$ 12.8
Locomotive Line Haul	0	2	$ 1.6	$ 3.2
Total	63	25		$ 140.8

* Note that we have developed hardware costs for switchers based on a single large engine of, generally, over 2000 hp. However, many switchers are powered by several nonroad engines placed in series to arrive at a large horsepower locomotive. Perhaps it would have been more appropriate to assume research costs for those engines to be $0 since the effort is, presumably, being done for the nonroad Tier 4 rule. However, to be conservative, we have included engine line research costs for these engines.

Table 5-7 Tier 4 Engine Line Research Expenditures by Market Segment ($Million)

Segment	Engine Lines <600 kW	Engine Lines >600 kW	Tier 4 $/line	Total
Marine C1	n/a	10	$ 6.5	$ 65.0
Marine-C1/Loco-Switcher/Passenger	0	2	$ 6.5	$ 13.0
Locomotive Switcher/Passenger	6*	0	$ 3.2	$ 19.2
Marine C2	0	11	$ 6.5	$ 71.5
Marine-C2/Loco-LineHaul	0	2	$ 6.5	$ 13.0
Locomotive Line Haul	0	0	$ 6.5	$ 0
Total	6	25		$ 181.7

* Note that we have developed hardware costs for switchers based on a single large engine of, generally, over 2000 hp. However, many switchers are powered by several nonroad engines placed in series to arrive at a large horsepower locomotive. We could have assumed research costs for those engines to be $0 since the effort is, presumably, being done for the nonroad Tier 4 rule. However, to be conservative, we have included engine line research costs for these engines.

We estimate that these engine line research expenditures will be made over a five year period in advance of the standard for which the cost is incurred. Spreading the costs this way results in the annual cost streams shown in Table 5-8 for Tier 3 and Table 5-9 for Tier 4 and Table 5-10 for the proposed program (i.e., Tiers 3 and 4). [e]

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[e] Note that we show the Tier 3 engine-line research costs beginning in calendar year 2007 even though this rule will not be final until the end of 2007 at the earliest. While we usually do not account for investments made prior to a rule being finalized, we understand that manufacturers have

Table 5-8 Estimated Tier 3 Engine Line Research Expenditures by Year ($Millions)

Calendar Year	Locomotive Switchers			Locomotive Line Haul			Marine C1; Rec; small			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2008	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2009	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2010	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2011	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2014	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2015	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2016	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2017	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2018	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$4.2	$8.6	$12.8	$1.1	$2.1	$3.2	$34.3	$69.7	$104.0	$6.9	$13.9	$20.8	$140.8	$46.5	$94.3
NPV at 7%	$3.2	$6.6	$9.8	$0.8	$1.6	$2.5	$26.3	$53.4	$79.7	$5.3	$10.7	$15.9	$107.9	$35.6	$72.3
NPV at 3%	$3.8	$7.6	$11.4	$0.9	$1.9	$2.8	$30.5	$62.0	$92.5	$6.1	$12.4	$18.5	$125.2	$41.3	$83.9

Table 5-9 Estimated Tier 4 Engine Line Research Expenditures by Year ($Millions)

Calendar Year	Locomotive Switchers			Locomotive Line Haul			Marine C1 > 600 kW			Marine C2			Totals		
	PM	NO$_X$+ NMHC	Subtotal	PM	NO$_X$+ NMHC	Subtotal	PM	NO$_X$+ NMHC	Subtotal	PM	NO$_X$+ NMHC	Subtotal	Total Spent	PM	NO$_X$+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2008	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2009	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2010	$1.7	$ -	$1.7	$0.4	$ -	$0.4	$ -	$ -	$ -	$ -	$ -	$ -	$2.1	$2.1	$ -
2011	$1.7	$ -	$1.7	$0.4	$ -	$0.4	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$32.0	$12.0	$20.0
2012	$1.7	$3.4	$5.1	$0.4	$0.9	$1.3	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$36.3	$12.0	$24.3
2013	$1.7	$3.4	$5.1	$0.4	$0.9	$1.3	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$36.3	$12.0	$24.3
2014	$1.7	$3.4	$5.1	$0.4	$0.9	$1.3	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$36.3	$12.0	$24.3
2015	$ -	$3.4	$3.4	$ -	$0.9	$0.9	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$34.2	$9.9	$24.3
2016	$ -	$3.4	$3.4	$ -	$0.9	$0.9	$ -	$ -	$ -	$ -	$ -	$ -	$4.3	$ -	$4.3
2017	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2018	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$8.5	$17.2	$25.7	$2.1	$4.4	$6.5	$23.6	$47.9	$71.5	$25.7	$52.3	$78.0	$181.7	$60.0	$121.7
NPV at 7%	$5.3	$9.4	$14.7	$1.3	$2.4	$3.7	$13.8	$28.0	$41.8	$15.0	$30.6	$45.6	$105.8	$35.5	$70.4
NPV at 3%	$6.9	$13.2	$20.1	$1.7	$3.3	$5.1	$18.6	$37.8	$56.5	$20.3	$41.3	$61.6	$143.3	$47.6	$95.7

Table 5-10 Estimated Tier 3 & Tier 4 Engine Line Research Expenditures by Year ($Millions)

Calendar Year	Locomotive Switchers			Locomotive Line Haul			Marine C1; Rec; small			Marine C2			Totals		
	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	PM	NO_X+ NMHC	Subtotal	Total Spent	PM	NO_X+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2008	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2009	$0.8	$1.7	$2.6	$0.2	$0.4	$0.6	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$28.2	$9.3	$18.9
2010	$2.5	$1.7	$4.3	$0.6	$0.4	$1.1	$6.9	$13.9	$20.8	$1.4	$2.8	$4.2	$30.3	$11.4	$18.9
2011	$2.5	$1.7	$4.3	$0.6	$0.4	$1.1	$11.6	$23.5	$35.1	$6.5	$13.2	$19.8	$60.2	$21.3	$38.9
2012	$1.7	$3.4	$5.1	$0.4	$0.9	$1.3	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$36.3	$12.0	$24.3
2013	$1.7	$3.4	$5.1	$0.4	$0.9	$1.3	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$36.3	$12.0	$24.3
2014	$1.7	$3.4	$5.1	$0.4	$0.9	$1.3	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$36.3	$12.0	$24.3
2015	$ -	$3.4	$3.4	$ -	$0.9	$0.9	$4.7	$9.6	$14.3	$5.1	$10.5	$15.6	$34.2	$9.9	$24.3
2016	$ -	$3.4	$3.4	$ -	$0.9	$0.9	$ -	$ -	$ -	$ -	$ -	$ -	$4.3	$ -	$4.3
2017	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2018	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$12.7	$25.8	$38.5	$3.2	$6.5	$9.7	$57.9	$117.6	$175.5	$32.6	$66.2	$98.8	$322.5	$106.4	$216.1
NPV at 7%	$8.5	$16.0	$24.5	$2.2	$4.0	$6.2	$40.1	$81.4	$121.5	$20.3	$41.2	$61.5	$213.8	$71.1	$142.7
NPV at 3%	$10.7	$20.8	$31.5	$2.7	$5.2	$7.9	$49.2	$99.8	$149.0	$26.4	$53.7	$80.1	$268.5	$88.9	$179.6

Table 5-10 shows the total estimated costs associated with engine line research. This table combines the costs for Tier 3 (Table 5-8) and Tier 4 (Table 5-9). As shown in Table 5-10, the net present value of the engine line research is estimated at $269 million using a three percent discount rate and $214 million using a seven percent discount rate. We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-11.

Table 5-11 Estimated Engine Line Research per Engine

	Estimated Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 31.5	3,212	$ 9,800
Locomotive Line Haul	$ 7.9	19,258	$ 410
Small Marine	$ 7.1	324,403	$ 20
Recreational Marine	$ 23.8	432,523	$ 60
Marine C1 <600 kW	$ 44.5	303,024	$ 150
Marine C1 >600 kW	$ 73.6	25,597	$ 2,870
Marine C2	$ 80.1	6,647	$12,050
Total	$ 268.5	1,114,666	$ 240

Note: Marine C1 >600 kW includes recreational marine ≥ 2000 kW. Net present values of sales are calculated using zero as the sales figure for 2006.

5.2.1.2 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 heavy-duty highway rule, we estimated approximately $1.6 million per engine line for tooling costs associated with DPF/NO_x aftertreatment systems. For the NRT4 rule, we estimated that a manufacturer that sold only into the landbased nonroad market would incur the same amount – $1.65 million expressed in 2002 dollars – for each engine line that required a DPF/NO_x aftertreatment system. In this rule, we estimate the same level of tooling costs associated with DPF/NO_x aftertreatment for those manufacturers selling only into the locomotive/marine markets, or $1.8 million in 2005 dollars. We have estimated the same level of tooling costs as in the 2007 highway and NRT4 rules because we expect new locomotive/marine engines to use technologies with similar tooling needs (i.e., a DPF and a NO_x aftertreatment device). For those manufacturers that sell into the highway and/or nonroad markets and have, therefore, already made considerable tooling investments, we have estimated an expenditure of 25 percent of this amount, or $450,000, for those engine lines that will require DPF/NO_x aftertreatment systems for the locomotive/marine market. These costs are assigned equally to NO_x+NMHC control and PM control since the tooling for one should be no more costly than that for the other.

The tooling estimates discussed above represent our estimates, per engine line, for engine lines expected to meet the Tier 4 requirements. As noted above in our discussion of engine line research, we estimate 31 engine lines that will incur these costs. Of those 31 lines, we estimate that five belong to manufacturers selling exclusively into the locomotive and/or marine markets. The remaining 26 lines belong to manufacturers that also sell into the highway and/or nonroad markets. The resultant tooling expenditures associated with the Tier 4 standards are then $22.1 million.

For meeting the Tier 3 requirements, we have estimated lower costs per line because the engines will require far less in terms of new hardware and, in fact, are expected only to require upgrades to existing hardware (i.e., new fuel systems). As such, we have estimated that those manufacturers selling exclusively into the locomotive and/or marine markets will spend $450,000 per engine line, while manufacturers that also sell into the highway and/or nonroad markets will spend $180,000 per engine line. The PSR database shows 88 engine lines that we expect to meet the Tier 3 standards, 13 of which belong to manufacturers that sell only into the locomotive and/or marine markets. The resultant tooling expenditures associated with the Tier 3 standards are then $19.4 million. As with the Tier 4 tooling costs, these costs are assigned equally to NO_x control and PM control.

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-, or eight-cylinder engine may be produced from the same basic engine design. While these engines have different total displacement, they each 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 market segments. To allocate the tooling expenditure for a given production line to a specific market segment, we have divided costs equally among the segments (i.e., an engine line used in both the marine C1 and the locomotive switchers segments would have its tooling costs split evenly between those two segments).

We estimate that the tooling expenditures would be made one year in advance of meeting the standards for which the money is spent. A summary of the tooling costs per manufacturer are shown in Table 5-12. The tooling costs by market segment are shown in Table 5-13 and the annual cost streams are shown in Table 5-14.

Table 5-12 Estimated Tooling Expenditures by Type of Engine Manufacturer Totals per Engine Line ($Million)

	Tier 3 engine lines	Tier 4 engine lines
Manufacturer sells into highway and/or nonroad markets	$ 0.18	$ 0.45
Manufacturer sells only into locomotive and/or marine markets	$ 0.45	$ 1.8
% allocated to PM	50%	50%
% allocated to NO_x+NMHC	50%	50%

Note: We have arbitrarily attributed the tooling costs equally to NO_x+NMHC and PM control because we have no reason to believe that the tooling costs would be greater for one than the other.

Table 5-13 Estimated Engine Tooling Expenditures by Market Segment and Tier ($Million)

Segment	Tier 3	Tier 4	Total
Marine C1 <600 kW	$ 7.9	$ 0	$ 7.9
Marine C1 >600 kW	$ 1.9	$ 7.8	$ 9.7
Marine C2	$ 2.6	$ 8.9	$ 11.5
Marine Recreational	$ 4.2	$ 0	$ 4.2
Marine Small	$ 1.2	$ 0	$ 1.2
Locomotive Switcher	$ 1.0	$ 3.1	$ 4.1
Locomotive Line Haul	$ 0.6	$ 2.3	$ 2.8
Total	$ 19.4	$ 22.1	$ 41.4

Note: Marine C1 >600 kW includes recreational marine $\geq$ 2000 kW.

Table 5-14 Estimated Tier 3 and Tier 4 Engine Tooling Expenditures by Year ($Millions)

Calendar Year	Locomotive			Marine					Totals		
	Switchers	Line-Haul	Subtotal	Marine C1	Marine C2	Recreational	Small	Subtotal	Total Spent	PM	NO_X+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2008	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2009	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2010	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2011	$1.0	$0.6	$1.6	$9.8	$2.6	$4.2	$1.2	$17.8	$19.4	$9.7	$9.7
2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2014	$1.6	$1.1	$2.7	$ -	$ -	$ -	$ -	$ -	$2.7	$2.7	$ -
2015	$ -	$ -	$ -	$7.8	$8.9	$ -	$ -	$16.7	$16.7	$8.3	$8.3
2016	$1.6	$1.1	$2.7	$ -	$ -	$ -	$ -	$ -	$2.7	$ -	$2.7
2017	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2018	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$4.1	$2.8	$6.9	$17.6	$11.5	$4.2	$1.2	$34.5	$41.4	$20.7	$20.7
NPV at 7%	$2.3	$1.5	$3.8	$10.5	$6.2	$2.8	$0.8	$20.3	$24.1	$12.1	$12.0
NPV at 3%	$3.2	$2.1	$5.3	$14.0	$8.8	$3.5	$1.0	$27.3	$32.6	$16.4	$16.2

As shown in Table 5-14, the net present value of the engine tooling expenditures are estimated at $33 million using a three percent discount rate, and $24 million using a seven percent discount rate. We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-15.

Table 5-15 Estimated Engine Tooling Costs per Engine

	Estimated Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 3.2	3,212	$ 980
Locomotive Line Haul	$ 2.1	19,258	$ 110
Small Marine	$ 1.0	324,403	$ 3
Recreational Marine	$ 3.5	432,523	$ 10
Marine C1 <600 kW	$ 8.2	303,024	$ 30
Marine C1 >600 kW	$ 5.8	25,597	$ 230
Marine C2	$ 8.8	6,647	$ 1,320
Total	$ 32.6	1,114,666	$ 30

Note: Net present values of sales are calculated using zero as the sales figure for 2006.

5.2.1.3 Engine Certification Costs

Manufacturers would incur more than the normal level of certification costs during the first few years of implementation because all engines would need to be fully certified to the new emission standards rather than using the normal practice of carrying certification data over from prior years.[f] Consistent with our past locomotive and marine standard setting regulations, we have estimated engine certification costs as shown in Table 5-16. These costs are consistent with past rulemakings, but have been updated to 2005 dollars. Certification costs (for engines in all market segments) apply equally to all engine families for all manufacturers regardless of the markets into which the manufacturer sells.

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[f] Note that all engines are certified every year, but most annual certifications involve carrying over test data from prior years since the engine being certified has not changed in an "emissions-meaningful" way. Since new standards preclude use of carry-over data, we estimate new certification costs for all engines. Note that this is, effectively, a conservative estimate since some engines would have changed sufficiently absent our new standards to require new certification data.

Table 5-16 Certification Costs per Engine Family

	$/engine family	# of engine families
Locomotive	$ 42,000	46
Small marine	$ 32,000	24
Marine C1 0.9<L/cyl<1.2	$ 32,000	7
Marine C1 1.2<L/cyl<2.5	$ 43,000	19
Marine C1 L/cyl>2.5	$ 54,000	13
Marine C2 L/cyl>5	$ 54,000	5

To determine the number of engine families to be certified, we looked at our certification databases for the 2004 model year. For marine engines, our database provides the number of engine families, the liters per cylinder for each, and specifies whether it is certified as a C1 or a C2 engine. For locomotive engines, the database provides the engine displacement. We have also split the Marine C1 certification costs evenly between the C1 Marine and Recreational Marine market segments in the Tier 3 timeframe. In the Tier 4 timeframe, only those C1 Marine engines over 600 kW, including those recreational marine engines over 2000 kW, would incur certification costs since those C1 engines under 600 kW and the remaining recreational marine engines will not be meeting the Tier 4 standards. For the small marine segment, we have estimated the number of engine families at 24 based on an estimated two families per each of 10 manufacturers selling into that market, and then another four families sold by marinizers. The costs for small marine would be incurred only in the Tier 3 timeframe since they will not be meeting the Tier 4 standards. Similarly, the locomotive certification costs have been split evenly between locomotive switchers and locomotive line haul for both Tiers 3 and 4. The resultant annual cost streams are shown in Table 5-17. As shown in the table, the Tier 3 certification costs are estimated at $4.7 million, while the Tier 4 certification costs are estimated at around $4.5 million. Despite fewer engines being certified in the Tier 4 timeframe, the costs are roughly equal to the Tier 3 costs because, for the Tier 4 standards, we have estimated that locomotive engines are certified twice, once for the new PM standard and a second time two years later for the new NO_x standard.

The total certification expenditures are estimated at $9.3 million, or $7.3 million at a three percent discount rate and $5.5 million at a seven percent discount rate. The table also makes clear what portion of costs are allocated to NO_x+NMHC and PM, with a 50/50 allocation associated with the Tier 3 standards and the marine Tier 4 standards. The locomotive Tier 4 certification cost allocations align with the Tier 4 standards (PM costs first and NO_x+NMHC costs two years later).

We can estimate these expenditures on a per engine basis considering the time value of money and engine sales for 2006 through 2040, as shown in Table 5-18.

Table 5-17 Estimated Engine Certification Costs by Year ($Millions)

Calendar Year	Locomotive		Marine				Totals		
	Switchers	Line-Haul	Marine C2	Marine C1	Recreational	Small	Total Spent	PM	NO_X+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2008	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2009	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2010	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2011	$1.0	$1.0	$0.3	$0.9	$0.9	$0.8	$4.7	$2.4	$2.4
2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2014	$1.0	$1.0	$ -	$ -	$ -	$ -	$1.9	$1.9	$ -
2015	$ -	$ -	$0.3	$0.4	$ -	$ -	$0.7	$0.4	$0.4
2016	$1.0	$1.0	$ -	$ -	$ -	$ -	$1.9	$ -	$1.9
2017	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2018	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2019	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2020	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2021	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2022	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2023	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2025	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2026	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2027	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2028	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2029	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2030	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2031	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2032	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2036	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2037	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2038	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2039	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2040	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	$2.9	$2.9	$0.5	$1.3	$0.9	$0.8	$9.3	$4.6	$4.6
NPV at 7%	$1.6	$1.6	$0.3	$0.8	$0.6	$0.5	$5.5	$2.8	$2.7
NPV at 3%	$2.2	$2.2	$0.4	$1.1	$0.7	$0.6	$7.3	$3.7	$3.6

Table 5-18 Estimated Engine Certification Costs per Engine

	Estimated Total Cost Allocation ($Millions)	Estimated Sales from 2006 to 2040	$/engine
Locomotive Switcher/Passenger	$ 2.2	3,212	$ 700
Locomotive Line Haul	$ 2.2	19,258	$ 120
Small Marine	$ 0.6	324,403	$ 2
Recreational Marine	$ 0.7	432,523	$ 2
Marine C1	$ 1.1	328,621	$ 3
Marine C2	$ 0.4	6,647	$ 60
Total	$ 7.3	1,114,666	$ 10

Note: Net present values of sales are calculated using zero as the sales figure for 2006.

Note that these certification costs may overestimate actual costs because they assume all engines would be certified as a result of the proposed new emission standards. However, some engines would have been scheduled for new certification independent of the proposed new standards due to design changes or power increases among other possible reasons. For such engines, the incremental certification cost would be zero. However, to remain conservative, here we have applied the certification costs to all engine families.

5.2.2 New Engine Variable Engineering Costs

Engine variable costs are those costs for new hardware required to meet the new Tier 4 emission standards. We have estimated no incremental hardware costs associated with the Tier 3 standards. Unlike the Tier 4 standards, the proposed Tier 3 standards are not based on the introduction of new emission control technologies on locomotive or marine diesel engines. Rather, the Tier 3 standards represent the largest level of emission reductions possible from the emission control systems we project that locomotive and marine engines will already have in the timeframe of Tier 3 implementation. For example, the marine Tier 3 standards are predicated on the use of the most modern nonroad Tier 4 base engine technologies without the use of the nonroad Tier 4 aftertreatment based emission solutions. While these base engines may represent significant technical advances from the marine Tier 2 engines they replace—having better high pressure fuel systems, better injectors, improved turbochargers, and more sophisticated electronic control units—we do not expect the manufacturing costs for these individual components to increase over the cost of the Tier 2 components they will replace. In fact, the shift from the Tier 2 engine's electronic unit pump system to the Tier 3 engine's common rail fuel system may actually result in a fuel system that is cheaper to produce, not more expensive. Similarly, while the processing power of the Tier 3 engine control computer may increase significantly, the cost of the computer chip that makes this possible is likely to be lower. This does not mean that the Tier 3 emission controls come for free. We project there will be costs incurred to optimize the control strategies to meet the stringent Tier 3 standards and further to test and certify these engines. These costs are accounted for as fixed costs described further in section 5.2.1 of this draft RIA.[g]

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[g] To clarify, we have analyzed the fixed costs associated with the switch from unit injectors to common rail fuel systems reflecting our belief that this transition will come in part because of our regulation. Because we estimate that common rail fuel systems will be no more expensive than unit injector systems, and may in fact be cheaper, we have made no estimate of an incremental increase in variable costs due to this switch. Similarly, we have not made an estimate of what savings (if any) might be realized from this switch.

For the variable cost estimates presented here, we have used the same methodology to estimate costs as was used in our 2007 highway and our NRT4 rules. Because of the wide variation of engine sizes in the locomotive and marine markets, we have chosen an approach that results not in a specific cost per engine for engines within a given power range or market segment, 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. Using the equations presented in this section, we have then estimated the engine variable costs for the sales weighted average engine in different power ranges within each market segment.[h]

The discussion here considers both near-term and long-term cost estimates. We believe there are factors that cause 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.[9]

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”). 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.[10] The distribution of these progress ratios is shown in Figure 5-1. 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

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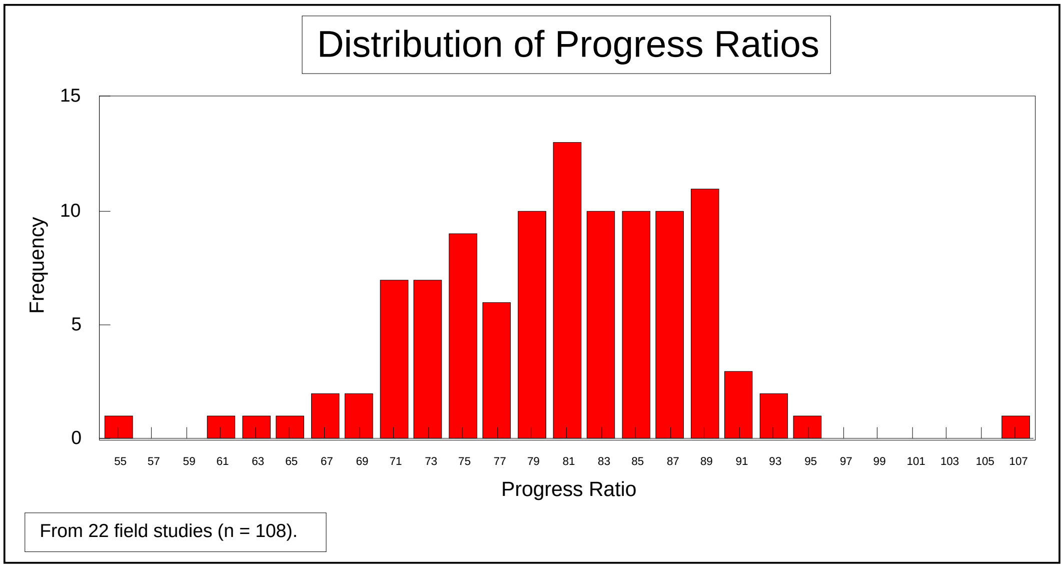
[h] For example, if two engines are sold with one being 100 hp and having 5 sales, the other being 200 hp and having 20 sales, the sales weighted horsepower of engines sold would not be 150 hp but would instead be 180 hp (100x5 + 200x20 = 4,500; 4,500/25 = 180).

value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

Figure 5-1 Distribution of Progress Ratios (Dutton and Thomas 1984)



From 22 field studies (n = 108).

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 percent decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

We believe 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. Neither locomotive nor marine diesel engines currently use any form of NO_x or PM aftertreatment except in very limited retrofit applications. Therefore, these are new technologies for these engines and will involve some new manufacturing operations, new parts, and new assembly operations beyond those anticipated in response to the 2007 highway and NRT4 rules. Since this will be a new product, we believe this is an appropriate situation for the learning curve concept to apply. Opportunities will exist to reduce unit labor and material costs and increase productivity as discussed above. We believe a similar opportunity exists for the new control systems that will integrate the function of the engine and emission-control technologies. While impacted 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 electronic fuel systems including common rail systems—they will be applied in some new ways in response to the 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 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 market segment. Because the timing of the emission standards in this final rule follows that of the 2007 highway and NRT4 rules, we have used the first stage of learning done via those rules collectively as the starting point of learning for locomotive and marine engines. In other words, one learning phase is factored into the baseline costs for locomotive/marine engines. We have then applied one additional learning step from that baseline. In the 2007 highway rule, we applied a second learning step following the second doubling of production estimated to occur at the end of the 2010 model year. We could have chosen that point as our baseline case for this rule and then applied a single learning curve effect from there. Instead, to remain conservative, we have chosen to use only the first learning step from the highway/nonroad rules. The approach taken here is consistent with the approaches taken in our Tier 2 light-duty highway rule and the 2007 highway 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 is less opportunity for lowering production costs. For that reason, we applied only one learning curve effect. The situation is similar for locomotive and marine engines. Because these will be existing technologies by the time they are introduced into the market, there would arguably be less opportunity for learning than there will be for the highway engines on which the technologies were first introduced.

Another factor that plays into our near-term and long-term cost estimates is that for warranty claim rates. In our 2007 highway 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.[11] As a result, in our NRT4 rule, we applied a three percent warranty claim rate during the first two years and then one percent warranty claim rate thereafter. We have used the same approach here as used in the NRT4 rule. 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.

5.2.2.1 SCR System Costs

The NO_x aftertreatment system anticipated for the Tier 4 standards is the selective catalytic reduction (SCR) system. For the SCR system to function properly, a systems approach that includes a reductant metering system and control of engine-out NO_x emissions is necessary. Many of the new air handling and electronic system technologies developed to meet past locomotive and marine standards, and past highway and nonroad standards can be applied to accomplish the SCR system control functions as well. Some additional hardware for exhaust NO_x or oxygen sensing may also be required.

We have used the same methodology to estimate costs associated with SCR systems as was used in our 2007 highway and NRT4 rulemakings for other aftertreatment devices. The basic components of the SCR system are well known and include the following material elements:

- a ceramic substrate upon which a NO_x catalyst washcoating is applied;
- a can to hold and support the substrate;
- a urea dosing unit (urea injector and control computer);
- a urea storage tank and associated brakets; and,
- an exhaust gas sensor (e.g., a NO_x sensor) used for control.

Examples of these material costs are summarized in Table 5-19 and represent costs to the engine manufacturers inclusive of supplier markups. The manufacturer costs shown in Table 5-19 include additional markups to account for both manufacturer and dealer overhead and carrying costs. The application of overhead and carrying costs is consistent with the approach taken in the 2007 highway and NRT4 rulemakings. In those rules, we estimated the markup for catalyzed emission-control technologies based on input from catalyst manufacturers. Specifically, we were told that device manufacturers could not mark up the cost of the individual components within their products because those components consist of basic commodities (for example, precious metals used in the catalyst could not be arbitrarily marked up because of their commodity status). Instead, manufacturing entities could mark up costs only where they add a unique value to the product. In the case of catalyst systems, 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 realized by the catalyst manufacturer. In essence, these are components to which the supplier provides little value-added engineering.

The one component that is unique to each catalyst manufacturer (i.e., the component where they add a unique value) is the catalyst washcoat support materials. This mixture (which is effectively 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 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 SCR systems and DPF systems. 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 cost to account for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. A dealer carrying cost is also 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.[12] Also included is our estimate of warranty costs for the system.

Table 5-19 SCR System Costs (costs shown are costs per SCR system for the given engine power/displacement)

Typical Engine Power (kW)	7	25	57	187	375	746	3730
Typical Engine Displacement (Liter)	0.4	1.5	3.9	7.6	18.0	34.5	188.0
Material and component costs							
Catalyst Volume (Liter)	1.0	3.8	9.8	19.1	45.0	86.3	470.0
Substrate	$29	$113	$294	$573	$1,350	$2,588	$14,100
Washcoating and Canning	$423	$517	$721	$1,035	$1,910	$3,302	$16,258
Platinum	$0	$0	$0	$0	$0	$0	$0
Catalyst Can Housing	$12	$12	$13	$15	$20	$28	$100
Urea Dosing Unit (Injection Assembly w/ ECU)	$500	$527	$585	$674	$922	$1,318	$5,000
Urea Solution Tank & Brackets	$2	$8	$18	$60	$121	$240	$1,200
NO_x sensor (1 sensor/engine)	$200	$200	$200	$200	$200	$200	$200
DOC for cleanup	$233	$245	$271	$312	$425	$605	$2,280
Direct Labor Costs							
Estimated Labor hours	4	4	4	4	4	8	8
Labor Rate ($/hr)	$18	$18	$18	$18	$18	$18	$18
Labor Cost	$72	$72	$72	$72	$72	$145	$145
Labor Overhead @ 40%	$29	$29	$29	$29	$29	$58	$58
Total Direct Costs to Mfr.	$1,501	$1,723	$2,204	$2,971	$5,049	$8,484	$39,341
Warranty Cost (3% claim rate)	$111	$128	$164	$221	$377	$627	$2,941
Mfr. Carrying Cost - Near term	$60	$69	$88	$119	$202	$339	$1,574
Total Cost to Dealer - Near term	$1,672	$1,919	$2,456	$3,311	$5,628	$9,450	$43,856
Dealer Carrying Cost - Near term	$50	$58	$74	$99	$169	$283	$1,316
Baseline Cost to Buyer - Near term	$1,722	$1,977	$2,530	$3,410	$5,797	$9,733	$45,171
Loco/Marine Cost to Buyer (includes highway learning) - Near term	**$1,377**	**$1,581**	**$2,024**	**$2,728**	**$4,638**	**$7,787**	**$36,137**
Warranty Cost (1% claim rate)	$37	$43	$55	$74	$126	$209	$980
Mfr. Carrying Cost - Long term	$60	$69	$88	$119	$202	$339	$1,574
Total Cost to Dealer - Long term	$1,598	$1,834	$2,347	$3,163	$5,377	$9,032	$41,895
Dealer Carrying Cost - Long term	$48	$55	$70	$95	$161	$271	$1,257
Baseline Cost to Buyer - Long term	$1,646	$1,889	$2,418	$3,258	$5,538	$9,303	$43,152
Baseline Cost to Buyer (includes Highway Learning) - Long term	$1,317	$1,511	$1,934	$2,606	$4,431	$7,442	$34,521
Loco/Marine Cost to Buyer (includes Loco/Marine learning) - Long term	**$1,053**	**$1,209**	**$1,547**	**$2,085**	**$3,544**	**$5,954**	**$27,617**

We have estimated the cost of this system based on information from several reports.[13, 14, 15] The individual estimates and assumptions used to estimate the cost for the system are touched upon in the following paragraphs.

SCR Catalyst Volume

During development of this proposal, engine and aftertreatment device manufacturers have indicated that SCR catalyst volumes could be from one to three times engine displacement for locomotive and marine applications. As explained in Chapter 4 of this draft RIA, we have used a ratio of SCR volume to engine displacement equal to 2.5:1.

SCR Catalyst Substrate

The ceramic flow-through substrates used for the SCR catalyst were estimated to cost $30 per liter.

SCR Catalyst 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). 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 other components that are 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 5-19 represent costs with manufacturer markups included. The washcoating and canning costs can be expressed as $34(x) + $390, where x is the catalyst volume in liters. This washcoating cost is higher than our past rulemakings because of dual washcoating process we anticipate will be used to “zone coat” the diesel oxidation function onto a portion of the SCR catalyst (as discussed below).

SCR Catalyst Precious Metals

We expect that the SCR catalysts used in locomotive and marine applications will contain no precious metals (e.g., the platinum group metals platinum, palladium, and rhodium). As a result, we have estimated zero costs associated with these commodities.

SCR Can Housing

The material cost for the can housing is estimated based on the catalyst volume plus 20 percent for transition (inlet/outlet) cones, plus 20 percent for scrappage (material purchased but unused in the final product) and a price of $1 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2005.[16]

Urea Dosing Unit

The costs for the urea dosing unit are based in part on our past contractor report that estimated the costs at $250 to $300 for units meant for 12 to 26 liter catalysts. Here, we have adjusted the numbers based on recent conversations with industry by estimating the costs for the smallest engines at $500 and the largest at $5,000. We then used a linear interpolation to arrive at the costs for engines in between.

Urea Solution Tank and Brackets

The estimated costs for the urea solution tank and brackets is based on industry input that fuel tank size is roughly one gallon per engine horsepower and urea dosing rate is roughly four percent of the fueling rate. We also estimated that a urea tank would cost $60 per 10 gallons of volume. Using these estimates, the needed urea tank size and associated cost can be estimated.

NO_x Sensor Cost

We believe that one sensor will be needed per catalyst and have used an estimated cost of $200 per sensor based on today's cost of $300 for use in retrofit applications (retrofit applications are typically considerably more costly than new). With increased NO_x sensor sales volumes in future locomotive, marine, highway, and nonroad markets, we believe that NO_x sensor costs may well be in the $50 to $100 range, if not lower. For this analysis, we have chosen to remain conservative by using the $200 per sensor estimate.

DOC for Cleanup

Included in the costs for the SCR system are costs for a diesel oxidation catalyst (DOC) for clean-up of possible excess ammonia emissions that might occur as a result of excessive urea usage. The methodology used to estimate DOC costs is consistent with the SCR system cost methodology and is presented below in Table 5-20. These cost estimates use a DOC to engine displacement ratio of 0.5:1 because the low emissions conversion demand placed on the DOC is not expected to require a larger device.

Table 5-20 Diesel Oxidation Costs (costs shown are costs per SCR system for the given engine power/displacement)

Typical Engine Power (kW)	7	25	57	187	375	746	3730
Typical Engine Displacement (Liter)	0.4	1.5	3.9	7.6	18.0	34.5	188.0
Material and component costs							
Catalyst Volume (liter)	0.2	0.8	2.0	3.8	9.0	17.3	94.0
	$0	$0	$0	$0	$0	$0	$0
Substrate	$187	$195	$212	$238	$310	$424	$1,491
Washcoating and Canning	$1	$4	$10	$19	$46	$88	$480
Platinum Catalyst Can Housing	$0	$0	$0	$0	$0	$0	$0
Direct Labor Costs							
	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Estimated Labor hours Labor Rate ($/hr)	$18	$18	$18	$18	$18	$18	$18
Labor Cost	$9	$9	$9	$9	$9	$9	$9
Labor Overhead @ 40%	$4	$4	$4	$4	$4	$4	$4
Total Direct Costs to Mfr.	$201	$212	$235	$270	$368	$525	$1,984
Warranty Cost - Near Term (3% claim rate)	$17	$18	$20	$22	$30	$41	$151
Mfr. Carrying Cost - Near Term	$8	$8	$9	$11	$15	$21	$79
Total Cost to Dealer - Near Term	$226	$238	$264	$303	$413	$588	$2,214
Dealer Carrying Cost - Near Term	$7	$7	$8	$9	$12	$18	$66
Loco/Marine Cost to Buyer	**$233**	**$245**	**$271**	**$312**	**$425**	**$605**	**$2,280**

Important to note here is that we expect the DOC function to be fulfilled within the confines of the SCR catalyst using a process known as "zone coating" by which the DOC washcoat is applied to the tail end of the SCR catalyst substrate. By doing this, a physically separate DOC is not necessary. We have remained conservative in our cost analysis by including costs associated with canning of the DOC.

Direct Labor Costs

The direct labor costs for the catalyst are estimated based on 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 costs.

SCR Warranty Costs

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.[17] 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 7 kW engine shown in Table 5-19 is as follows:

[($29+$423+$12+$500+$2+$200+$233)(2.5) + ($50)(4hours)](3%) = $111

Manufacturer and Dealer Carrying Costs

The manufacturer's carrying cost was estimated at 4 percent 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 percent of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.

SCR System Cost Estimation Function

Using the example SCR system costs shown in the table, we calculated a linear regression to determine the SCR system cost as a function of engine displacement. This way, the function can be applied to the wide array of engines in the locomotive line haul and marine fleets to determine the total or per engine costs for SCR hardware. The functions calculated for SCR system costs in line-haul locomotives and marine applications are shown in Table 5-21.

For locomotive switcher applications, we have used the costs developed for our NRT4 rulemaking because locomotive switchers tend to be powered by land based nonroad engines. For this reason, it seemed most appropriate to use the same costs developed for that rule. These costs are also shown in Table 5-21.

Table 5-21 SCR System Costs as a Function of Engine Displacement, x, in Liters

		Linear Regression	R^2
Line haul locomotive; marine	Near-term cost function	\$185(x) + \$1,323	0.999
	Long-term cost function	\$142(x) + \$1,012	0.999
Switcher locomotive	Near-term cost function	\$103(x) + \$183	0.999
	Long-term cost function	\$83(x) + \$160	0.999

Note: Near term costs include a 3 percent warranty claim rate while long term costs include a 1 percent warranty claim rate and the learning effect.

This table shows both a near-term and a long-term cost function for SCR 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.

5.2.2.2 DPF System Costs

One means of meeting the proposed Tier 4 PM standard is to use a diesel particulate filter (DPF) system like that expected to be used for highway and NRT4 applications. However, as explained in Chapter 4 of this draft RIA, here we are projecting a DPF volume to engine displacement ratio of 1.7:1. In the highway and nonroad rules, we projected ratios of 1.5:1. For the DPF to function properly, a systems approach that includes precise control of engine air-fuel ratio is also necessary. Many of the new air handling and electronic fuel system technologies developed in order to meet the highway, nonroad, and past locomotive/marine standards can be applied to accomplish the DPF control functions as well.

We have used the same methodology to estimate costs associated with DPF systems as was used in our 2007 highway and NRT4 rulemakings. The basic components of the DPF are well known and include the following material elements:

- An oxidizing catalyst, typically platinum;
- a substrate upon which the catalyst washcoating is applied and upon which PM is trapped;

- a can to hold and support the substrate.

Examples of these material costs are summarized in Table 5-22 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 DPF 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. 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 based on industry input.[18]

Table 5-22 DPF System Costs (costs shown are costs per DPF system for the given engine power/displacement)

Typical Engine Power (kW)	7	25	57	187	375	746	3730
Typical Engine Displacement (Liter)	0.4	1.5	3.9	7.6	18.0	34.5	188.0
Material and component costs							
Filter Volume (Liter)	0.7	2.6	6.7	13.0	30.6	58.7	319.6
	$46	$176	$461	$898	$2,117	$4,057	$22,108
Filter Trap	$96	$111	$143	$192	$328	$546	$2,571
Washcoating and Canning	$41	$156	$408	$796	$1,874	$3,592	$19,575
Platinum Filter Can Housing	$9	$10	$11	$12	$16	$21	$74
Differential Pressure Sensor	$52	$52	$52	$52	$52	$52	$52
Direct Labor Costs							
	4	4	4	4	4	8	8
Estimated Labor hours Labor Rate ($/hr)	$18	$18	$18	$18	$18	$18	$18
Labor Cost	$72	$72	$72	$72	$72	$145	$145
Labor Overhead @ 40%	$29	$29	$29	$29	$29	$58	$58
Total Direct Costs to Mfr.	$345	$606	$1,175	$2,051	$4,488	$8,471	$44,583
Warranty Cost -- Near Term (3% claim rate)	$21	$41	$84	$149	$332	$623	$3,332
Mfr. Carrying Cost -- Near Term	$14	$24	$47	$82	$180	$339	$1,783
Total Cost to Dealer -- Near Term	$380	$671	$1,306	$2,282	$4,999	$9,433	$49,698
Dealer Carrying Cost -- Near Term	$11	$20	$39	$68	$150	$283	$1,491
Savings by removing silencer	($52)	($52)	($52)	($52)	($52)	($52)	($52)
Baseline Cost to Buyer -- Near Term	$340	$640	$1,293	$2,298	$5,098	$9,664	$51,137
Loco/Marine Cost to Buyer (includes highway learning) - Near term	**$272**	**$512**	**$1,035**	**$1,839**	**$4,078**	**$7,731**	**$40,910**
Warranty Cost -- Long Term (1% claim rate)	$7	$14	$28	$50	$111	$208	$1,111
Mfr. Carrying Cost -- Long Term	$14	$24	$47	$82	$180	$339	$1,783
Total Cost to Dealer -- Long Term	$366	$644	$1,250	$2,182	$4,778	$9,017	$47,477
Dealer Carrying Cost -- Long Term	$11	$19	$38	$65	$143	$271	$1,424
Savings by removing muffler	($52)	($52)	($52)	($52)	($52)	($52)	($52)
Baseline Cost to Buyer -- Long Term	$325	$611	$1,236	$2,196	$4,870	$9,236	$48,849
Baseline Cost to Buyer (includes Highway Learning) - Long term	$260	$489	$989	$1,757	$3,896	$7,389	$39,080
Loco/Marine Cost to Buyer (includes Loco/Marine learning) - Long term	**$208**	**$391**	**$791**	**$1,405**	**$3,117**	**$5,911**	**$31,264**

DPF Volume

During development of this proposal, engine manufacturers have suggested that DPF volumes could be up to three times engine displacement. The size of the DPF is based largely on 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 2007 highway and NRT4 rules, we estimated that the DPF would 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. As explained in Chapter 4 of this draft RIA, here we have estimated a ratio of 1.7:1.

DPF Substrate

The DPF can be made from a wide range of filter materials including wire mesh, sintered metals, fibrous media, or ceramic extrusions. The most common material used for DPFs for heavy-duty diesel engines is cordierite. Here we have based our cost estimates on the use of silicon carbide (SiC) even though it is more expensive than other filter materials. In the 2007 highway rule, we estimated that DPFs would consist of a cordierite filter costing \$30 per liter. To remain conservative in our cost estimates for nonroad applications, we assumed the use of silicon carbide filters costing double that amount, or \$60 per liter, because silicon carbide filters are more durable. As discussed in Chapter 4 of this draft RIA, we believe that metal substrates may be choice for locomotive and marine DPFs, which would cost less than a silicon carbide substrate. Nonetheless, to be conservative in our cost estimates, we have assumed use of silicon carbide filters for locomotive and marine applications, so have based costs on the \$60 per liter cost estimate. This cost is directly proportional to filter volume, which is proportional to engine displacement. We have converted the \$60 value to \$2005 using the Producer Price Index (PPI) for manufacturing industries; the end result being a cost of \$62 per liter.[19]

DPF Washcoating and Canning

These costs are based on costs developed under contract for our 2007 highway rule.[20] We converted those costs to \$2005 using the PPI for manufacturing industries. We then calculated a linear "best fit" to express the washcoating and canning costs as \$8(x) + \$91, where x is the DPF volume in liters.

DPF Precious Metals

The total precious metal content for DFPs is estimated to be 60 g/ft^3 with platinum as the only precious metal used in the filter. In our NRT4 rule, we used a price of \$542 per troy ounce for platinum. Here we have used the 2005 average monthly price of \$899 per troy ounce for platinum.[21]

DPF Can Housing

The material cost for the can housing is estimated based on the DPF volume plus 20 percent for transition (inlet/outlet) cones, plus 20 percent for scrappage (material purchased but unused in the final product) and a price of $1 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2005.

DPF Differential Pressure Sensor

We believe that the DPF 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.[22] A PPI adjusted cost of $52 per sensor has been used in this analysis.

DPF Direct Labor

Consistent with the approach for SCR systems, the direct labor costs for the DPF are estimated based on 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 costs.

DPF Warranty

Consistent with the approach taken for SCR system costs, 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 estimated 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.

DPF Manufacturer and Dealer Carrying Costs

Consistent with the approach for SCR systems, the manufacturer's carrying cost was estimated at four percent 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 three percent of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.

Savings Associated with Silencer Removal

DPF retrofits are often incorporated in, or are simply replacements for, the silencer (muffler) for diesel-powered vehicles and equipment. We believe that the DPF could be mounted in place of the silencer, although it may have slightly larger dimensions. We have estimated that applying a DPF allows for the removal of the silencer due to the noise attenuation characteristics of the DPF. We have accounted for this savings and have estimated a silencer costs at $52. The $52 estimate is an average for all engines; the actual savings will be higher for some and lower for others.

DPF System Cost Estimation Function

Using the example DPF costs shown in Table 5-22, we calculated a linear regression to determine the DPF system cost as a function of engine displacement. This way, the function can be applied to the wide array of engines in the locomotive line haul and/or marine fleets to determine the total or per engine costs for DPF system hardware. The functions calculated for DPF system costs for locomotive line-haul and marine applications are shown in Table 5-23.

For locomotive switcher applications, we have used the costs developed for our NRT4 rulemaking because locomotive switchers tend to be powered by land based nonroad engines making it appropriate to use the same costs developed for that rule. These costs are also shown in Table 5-23.

Table 5-23 DPF System Costs as a function of Engine Displacement, x, in Liters

		Linear Regression	R^2
Line-haul locomotive; marine	Near-term cost function	\$217(x) + \$199	0.999
	Long-term cost function	\$166(x) + \$153	0.999
Switcher locomotive	Near-term cost function	\$146(x) + \$75	0.999
	Long-term cost function	\$112(x) + \$57	0.999

Note: Near term costs include a 3 percent warranty claim rate while long term costs include a 1 percent warranty claim rate and the learning effect.

The near-term and long-term costs shown in Table 5-23 change due to the different warranty claim rates and the application of a 20 percent learning curve effect.

5.2.2.3 Aftertreatment Marinization Costs

For marine engines, the Tier 4 requirements will entail increased costs associated with marinizing the engines for the marine environment. Marine C1 and C2 engines are typically land based nonroad engines that are marinized for the marine environment. This marinization can take many forms, but is generally a matter of altering the cooling system to make use of sea or lake water rather than relying on ambient air since marine engines tend to be enclosed within vessels where ambient air radiators like those used in land based engines cannot operate efficiently. Such marinization efforts have been done for years and will continue but do not represent incremental costs associated with the new standards. Marinization costs associated with the new aftertreatment devices that would be added to comply with the Tier 4 standards—to control the surface temperatures in the typically tight space constraints onboard a vessel—do represent incremental costs associated with the proposed program and, thus, they must be considered.

Under contract to EPA, ICF International conducted a study that considered the costs associated with marinizing aftertreatment devices.[23] In their study, ICF looked at the costs associated with two methods of marinization: triple wall stainless steel; and, insulating blankets. Both methods could be used to control the surface temperature of the aftertreatment device such that accidental touching would not cause burns or otherwise compromise safety. The triple wall insulation method proved more cost efficient. Using this method, the device would, essentially, have three layers of stainless steel surrounding the substrate rather than the single layer normally used on land based engines. These layers would be separated by a few millimeters to provide an insulating air gap.

The ICF study looked at aftertreatment marinizing costs for a range of engine sizes in a manner similar to that discussed above for SCR and DPF systems. The details of these estimates are contained in the final report.[24] In the report, ICF calculated costs using a 1:1 or a 1.5:1 device volume to engine displacement ratio. However, as noted earlier, our analysis leads us to believe that a 2.5:1 ratio (SCR) and 1.7:1 ratio (DPF) are more applicable. As a result, we have adjusted the ICF results somewhat higher to reflect a larger sized device being insulated; these adjustments are reflected in Table 5-24 for marinization of SCR systems and in Table 5-25 for marinization of DPF systems. The resultant linear regression best fit curves for marinization costs as a function of engine displacement are shown in Table 5-26.

Table 5-24 SCR System Marinization Costs

Typical Engine Power (kW)	64	93	183	620	968	1425	1902	3805	5968
Typical Engine Displacement (L)	4.2	7	10.5	27	34.5	51.8	111	222	296
SCR Catalyst Marinization Hardware Cost	$23	$28	$29	$65	$77	$91	$173	$292	$350
Assembly	$0	$0	$0	$0	$0	$0	$0	$0	$0
Labor @ $28/hr	$3	$3	$3	$3	$3	$3	$3	$3	$3
Overhead @ 40%	$1	$1	$1	$1	$1	$1	$1	$1	$1
Total Assembly Cost	$4	$4	$4	$4	$4	$4	$4	$4	$4
Markup on Hardware and Assembly @ 29%	$8	$9	$9	$20	$24	$28	$51	$86	$103
Total SCR Catalyst Marinization Costs - Near term	$34	$42	$42	$90	$105	$123	$228	$382	$456
Total SCR Catalyst Marinization Costs - Long term	$27	$33	$34	$72	$84	$98	$182	$305	$365

Table 5-25 DPF System Marinization Costs

Typical Engine Power (kW)	64	93	183	620	968	1425	1902	3805	5968
Typical Engine Displacement (L)	4.2	7	10.5	27	34.5	51.8	111	222	296
DPF Marinization Hardware Cost	$15	$22	$29	$52	$61	$75	$112	$218	$262
Assembly	$0	$0	$0	$0	$0	$0	$0	$0	$0
Labor @ $28/hr	$3	$3	$3	$3	$3	$3	$3	$3	$3
Overhead @ 40%	$1	$1	$1	$1	$1	$1	$1	$1	$1
Total Assembly Cost	$4	$4	$4	$4	$4	$4	$4	$4	$4
Markup on Hardware and Assembly @ 29%	$6	$8	$9	$16	$19	$23	$34	$64	$77
Total DPF Marinization Costs - Near term	$25	$34	$42	$72	$84	$102	$150	$286	$343
Total DPF Marinization Costs - Long term	$20	$27	$34	$58	$67	$81	$120	$229	$274

Table 5-26 Marinization Costs as a function of Engine Displacement, x, in Liters

		Linear Regression	R^2
SCR System Marinization	Near-term cost function	\$1(x) + \$42	0.990
	Long-term cost function	\$1(x) + \$34	0.990
DPF System Marinization	Near-term cost function	\$1(x) + \$35	0.991
	Long-term cost function	\$1(x) + \$28	0.991

Note: Near term costs include a 3 percent warranty claim rate while long term costs include a 1 percent warranty claim rate and the learning effect.

5.2.2.4 Summary of Engine Variable Cost Equations

Engine variable costs are discussed in detail in sections 5.2.2.1 through 5.2.2.3. As described in those sections, we have generated cost estimation equations for SCR systems, DPF systems, and aftertreatment marinization as a function of engine displacement. These equations are summarized in Table 5-27. Note that not all equations were used for all engines and all market segments; equations were used in the manner shown in the table. We have calculated the aggregate engine variable costs and present them later in this chapter.

Table 5-27 Summary of Cost Equations for Engine Variable Costs (x represents the dependent variable)

Engine Technology	Time Frame	Cost Equation	Dependent Variable	How Used
SCR System Costs	Near term Long term	\$185(x) + \$1,323 \$142(x) + \$1,012	Engine Displacement (Liters)	Tier 4 Locomotive Line-haul and Marine Engines
SCR System Costs	Near term Long term	\$103(x) + \$183 \$83(x) + \$160	Engine Displacement (Liters)	Tier 4 Locomotive Switcher Engines
DPF System Costs	Near term Long term	\$217(x) + \$199 \$166(x) + \$153	Engine Displacement (Liters)	Tier 4 Locomotive Line-haul and Marine Engines
DPF System Costs	Near term Long term	\$146(x) + \$75 \$112(x) + \$57	Engine Displacement (Liters)	Tier 4 Locomotive Switcher Engines
SCR Marinization Costs	Near term Long term	\$1(x) + \$42 \$1(x) + \$34	Engine Displacement (Liters)	Tier 4 Marine Engines
DPF Marinization Costs	Near term Long term	\$1(x) + \$35 \$1(x) + \$28	Engine Displacement (Liters)	Tier 4 Marine Engines

Using these equations, we can calculate the variable costs associated with the Tier 4 standards for any engine provided we know its displacement, power, and intended application. We could do this for every compliant engine expected to be sold in the years following implementation of the new standards, total the results, and we would have the total annual variable costs associated with the rule. We can achieve essentially the same thing by calculating a sales weighted variable cost. This could be done for a single engine that could represent the entire fleet provided we sales weighted the critical characteristics of that engine. Doing this for one engine would not provide a particularly good look at the impact of the new standards on costs since the sizes of engines, their power, and use varies so much. Therefore, we have broken the fleet first into the market segments according to our regulatory definitions (i.e., marine C1, marine C2, locomotive, etc.). We have further broken each market segment into several power ranges, some of which are arbitrary and meant only to provide more stratification of the results, and some of which are chosen to align properly with the structure of the new standards (e.g., marine C1 has a power cutpoint at 600 kW since the Tier 4 standards apply to marine engines above 600 kW).

The necessary engine characteristics for sales weighting are engine displacement, power, and application. We have used the PSR database and sales figures from 2002. The resultant sales weighted engines within given market segments and power ranges are shown in Table 5-28.[i] For example, the sales weighted engine in the marine C1 segment, power range 800 to 2000 hp, has an engine displacement of 33.4 liters and is 1266 hp (944 kW). Empty cells in the table mean that there are no engines in that power range and market segment.

Table 5-28 Sales Weighted Engine Characteristics by Market Segment and Power Range

Power Range	Loco-LineHaul	Loco-Switcher	Marine C1	Marine C2	Marine Recreational	Small Marine
	Sales Weighted Displacement (Liters)					
0<hp<25						0.6
25<=hp<50						1.6
50<=hp<75		2.7	2.5		2.6	
75<=hp<200		5.8	5.5		5.0	
200<=hp<400		7.7	10.5		4.9	
400<=hp<800		18.9	17.6		8.8	
800<=hp<2000		51.8	33.4	93.0	28.9	
2000+	174.2	69.0	62.5	176.4	48.7	
	Sales Weighted Horsepower					
0<hp<25						15.8
25<=hp<50						36.0
50<=hp<75		67.0	58.2		61.1	
75<=hp<200		157.7	149.6		159.1	
200<=hp<400		227.3	301.1		269.7	
400<=hp<800		660.0	553.2		457.2	
800<=hp<2000		1500.0	1266.3	1508.6	1226.1	
2000+	4895.2	2000.0	2529.4	4014.5	2345.2	

Using these sales weighted engines shown in Table 5-28 and the variable cost equations shown in Table 5-27, we can calculate the individual piece costs for the various hardware elements expected to be added to engines to comply with the new standards. Those elements, as discussed above, being SCR systems, DPF systems, and costs associated with marinizing the SCR and the DPF systems (for marine engines only). The resultant piece costs are shown in Table 5-29. The table includes costs for engines in power ranges that are expected to add the new hardware or upgrade existing hardware. Empty cells reflect our belief that the technology will not be added as a result of our proposed rule. The rows containing data for “All engines” are costs for the sales weighted engine within each market segment. For Marine C1, we have also broken out the sales weighted costs for engines below and above 600 kW (805 hp). We use these values—those for “All engines” or, for the C1 marine

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[i] Note that the Marine C1 entries in the table include recreational marine engines over 2000 kW.

segment, those for “<600 kW” or “>600 kW”—for our total cost calculations presented in section 5.6.

Table 5-29 Piece Costs for Engine Hardware by Market Segment and Power Range

Power Range	Line-Haul	Switchers	Marine C1	Marine C2	Power Range	Line-Haul	Switchers	Marine C1	Marine C2
	SCR System Costs - Near term					SCR System Costs - Long term			
0<hp<25					0<hp<25				
25<=hp<50					25<=hp<50				
50<=hp<75		$460			50<=hp<75		$381		
75<=hp<200		$778			75<=hp<200		$635		
200<=hp<400		$979			200<=hp<400		$796		
400<=hp<800		$2,140			400<=hp<800		$1,723		
800<=hp<2000		$5,532	$7,514	$18,554	00<=hp<2000		$4,431	$5,743	$14,180
2000+	$33,591	$7,315	$12,904	$34,012	2000+	$25,672	$5,855	$9,862	$25,993
All engines	$33,591	$1,639		$30,502	All engines	$25,672	$1,323		$23,311
<800 hp only		$852			<800 hp only		$695		
>800 hp only		$6,449	$9,431		>800 hp only		$5,163	$7,209	
	SCR Marinization Costs - Near term					SCR Marinization Costs - Long term			
0<hp<25					0<hp<25				
25<=hp<50					25<=hp<50				
50<=hp<75					50<=hp<75				
75<=hp<200					75<=hp<200				
200<=hp<400					200<=hp<400				
400<=hp<800					400<=hp<800				
800<=hp<2000			$91	$178	800<=hp<2000			$73	$143
2000+			$133	$300	2000+			$107	$242
All engines				$272	All engines				$219
<800 hp only					<800 hp only				
>800 hp only			$106		>800 hp only			$85	
	DPF System Costs - Near term					DPF System Costs - Long term			
0<hp<25					0<hp<25				
25<=hp<50					25<=hp<50				
50<=hp<75		$467			50<=hp<75		$357		
75<=hp<200		$918			75<=hp<200		$702		
200<=hp<400		$1,203			200<=hp<400		$920		
400<=hp<800		$2,847			400<=hp<800		$2,177		
800<=hp<2000		$7,650	$7,437	$20,344	800<=hp<2000		$5,850	$5,684	$15,547
2000+	$37,924	$10,175	$13,738	$38,416	2000+	$28,982	$7,781	$10,499	$29,358
All engines	$37,924	$2,137		$34,312	All engines	$28,982	$1,634		$26,222
<800 hp only		$1,023			<800 hp only		$782		
>800 hp only		$8,949	$9,679		>800 hp only		$6,843	$7,397	
	DPF Marinization Costs - Near term					DPF Marinization Costs - Long term			
0<hp<25					0<hp<25				
25<=hp<50					25<=hp<50				
50<=hp<75					50<=hp<75				
75<=hp<200					75<=hp<200				
200<=hp<400					200<=hp<400				
400<=hp<800					400<=hp<800				
800<=hp<2000			$71	$135	800<=hp<2000			$57	$108
2000+			$102	$225	2000+			$82	$180
All engines				$205	All engines				$163
<800 hp only					<800 hp only				
>800 hp only			$82		>800 hp only			$66	

5.2.2.5 Annual Engine Variable Engineering Costs

Using the hardware piece costs shown in Table 5-29, we can calculate the annual costs for each market segment by multiplying piece costs by estimated future sales. Table 5-30 through Table 5-34 show these costs. These costs are associated with the Tier 4 standards since only Tier 4 engines are expected to incur new hardware costs. The PM/NO_x+NMHC cost allocations for engine variable costs used in this cost analysis are as follows: Urea SCR systems including marinization costs on marine applications are attributed 100% to NO_x+NMHC control; and DPF systems including marinization costs on marine applications are attributed 100% to PM control.

Table 5-30 Annual Locomotive Line-haul Engine Variable Costs; New Tier 4 Engines Only ($Millions)

Calendar Year	Sales	DPF	SCR	Total	PM	NO_X+ NMHC
2006		$ -	$ -	$ -	$ -	$ -
2007		$ -	$ -	$ -	$ -	$ -
2008		$ -	$ -	$ -	$ -	$ -
2009		$ -	$ -	$ -	$ -	$ -
2010		$ -	$ -	$ -	$ -	$ -
2011		$ -	$ -	$ -	$ -	$ -
2012	767	$ -	$ -	$ -	$ -	$ -
2013	765	$ -	$ -	$ -	$ -	$ -
2014	780	$ -	$ -	$ -	$ -	$ -
2015	816	$30.9	$ -	$30.9	$30.9	$ -
2016	854	$32.4	$ -	$32.4	$32.4	$ -
2017	877	$25.4	$29.4	$54.8	$25.4	$29.4
2018	894	$25.9	$30.0	$55.9	$25.9	$30.0
2019	917	$26.6	$23.6	$50.1	$26.6	$23.6
2020	948	$27.5	$24.3	$51.8	$27.5	$24.3
2021	979	$28.4	$25.1	$53.5	$28.4	$25.1
2022	1007	$29.2	$25.9	$55.0	$29.2	$25.9
2023	1034	$30.0	$26.6	$56.5	$30.0	$26.6
2024	1048	$30.4	$26.9	$57.3	$30.4	$26.9
2025	1078	$31.2	$27.7	$58.9	$31.2	$27.7
2026	1096	$31.8	$28.1	$59.9	$31.8	$28.1
2027	1119	$32.4	$28.7	$61.2	$32.4	$28.7
2028	1136	$32.9	$29.2	$62.1	$32.9	$29.2
2029	1150	$33.3	$29.5	$62.8	$33.3	$29.5
2030	1158	$33.6	$29.7	$63.3	$33.6	$29.7
2031	1173	$34.0	$30.1	$64.1	$34.0	$30.1
2032	1190	$34.5	$30.6	$65.0	$34.5	$30.6
2033	1209	$35.0	$31.0	$66.1	$35.0	$31.0
2034	1223	$35.5	$31.4	$66.9	$35.5	$31.4
2035	1231	$35.7	$31.6	$67.3	$35.7	$31.6
2036	1197	$34.7	$30.7	$65.4	$34.7	$30.7
2037	1172	$34.0	$30.1	$64.0	$34.0	$30.1
2038	1144	$33.2	$29.4	$62.5	$33.2	$29.4
2039	1112	$32.2	$28.6	$60.8	$32.2	$28.6
2040	1078	$31.2	$27.7	$58.9	$31.2	$27.7
NPV at 7%		$196.5	$152.5	$349.0	$196.5	$152.5
NPV at 3%		$426.6	$346.4	$773.0	$426.6	$346.4

Table 5-31 Annual Locomotive Switcher & Passenger Engine Variable Costs; New Tier 4 Engines Only ($Millions)

Calendar Year	Sales	DPF	SCR	Total	PM	NO_X+ NMHC
2006		$ -	$ -	$ -	$ -	$ -
2007		$ -	$ -	$ -	$ -	$ -
2008		$ -	$ -	$ -	$ -	$ -
2009		$ -	$ -	$ -	$ -	$ -
2010		$ -	$ -	$ -	$ -	$ -
2011		$ -	$ -	$ -	$ -	$ -
2012	92	$ -	$ -	$ -	$ -	$ -
2013	92	$ -	$ -	$ -	$ -	$ -
2014	93	$ -	$ -	$ -	$ -	$ -
2015	93	$0.9	$ -	$0.9	$0.9	$ -
2016	94	$1.0	$ -	$1.0	$1.0	$ -
2017	94	$0.7	$0.7	$1.4	$0.7	$0.7
2018	94	$0.7	$0.7	$1.4	$0.7	$0.7
2019	94	$0.7	$0.6	$1.3	$0.7	$0.6
2020	94	$0.7	$0.6	$1.3	$0.7	$0.6
2021	94	$0.7	$0.6	$1.3	$0.7	$0.6
2022	95	$0.7	$0.6	$1.3	$0.7	$0.6
2023	160	$1.2	$0.9	$2.2	$1.2	$0.9
2024	183	$1.4	$1.1	$2.5	$1.4	$1.1
2025	201	$1.6	$1.2	$2.7	$1.6	$1.2
2026	212	$1.6	$1.2	$2.9	$1.6	$1.2
2027	227	$1.8	$1.3	$3.1	$1.8	$1.3
2028	239	$1.9	$1.4	$3.3	$1.9	$1.4
2029	247	$1.9	$1.4	$3.4	$1.9	$1.4
2030	263	$2.0	$1.5	$3.6	$2.0	$1.5
2031	281	$2.2	$1.6	$3.8	$2.2	$1.6
2032	292	$2.3	$1.7	$4.0	$2.3	$1.7
2033	296	$2.3	$1.7	$4.0	$2.3	$1.7
2034	305	$2.4	$1.8	$4.2	$2.4	$1.8
2035	302	$2.3	$1.8	$4.1	$2.3	$1.8
2036	294	$2.3	$1.7	$4.0	$2.3	$1.7
2037	287	$2.2	$1.7	$3.9	$2.2	$1.7
2038	278	$2.2	$1.6	$3.8	$2.2	$1.6
2039	269	$2.1	$1.6	$3.7	$2.1	$1.6
2040	263	$2.0	$1.5	$3.6	$2.0	$1.5
NPV at 7%		$8.6	$5.9	$14.5	$8.6	$5.9
NPV at 3%		$20.4	$14.5	$35.0	$20.4	$14.5

Table 5-32 Annual C2 Marine Engine Variable Costs; New Tier 4 Engines Only ($Millions)

Calendar Year	Sales	DPF	SCR	Marinization	Total	PM	NO$_X$+ NMHC
2006		$ -	$ -	$ -	$ -	$ -	$ -
2007		$ -	$ -	$ -	$ -	$ -	$ -
2008		$ -	$ -	$ -	$ -	$ -	$ -
2009		$ -	$ -	$ -	$ -	$ -	$ -
2010		$ -	$ -	$ -	$ -	$ -	$ -
2011		$ -	$ -	$ -	$ -	$ -	$ -
2012	299	$ -	$ -	$ -	$ -	$ -	$ -
2013	301	$ -	$ -	$ -	$ -	$ -	$ -
2014	304	$ -	$ -	$ -	$ -	$ -	$ -
2015	307	$ -	$ -	$ -	$ -	$ -	$ -
2016	309	$10.6	$9.4	$0.1	$20.2	$10.7	$9.5
2017	312	$10.7	$9.5	$0.1	$20.4	$10.8	$9.6
2018	315	$8.3	$7.3	$0.1	$15.7	$8.3	$7.4
2019	318	$8.3	$7.4	$0.1	$15.9	$8.4	$7.5
2020	321	$8.4	$7.5	$0.1	$16.0	$8.5	$7.5
2021	324	$8.5	$7.5	$0.1	$16.2	$8.5	$7.6
2022	327	$8.6	$7.6	$0.1	$16.3	$8.6	$7.7
2023	330	$8.6	$7.7	$0.1	$16.4	$8.7	$7.7
2024	332	$8.7	$7.8	$0.1	$16.6	$8.8	$7.8
2025	335	$8.8	$7.8	$0.1	$16.7	$8.9	$7.9
2026	338	$8.9	$7.9	$0.1	$16.9	$8.9	$8.0
2027	342	$9.0	$8.0	$0.1	$17.0	$9.0	$8.0
2028	345	$9.0	$8.0	$0.1	$17.2	$9.1	$8.1
2029	348	$9.1	$8.1	$0.1	$17.4	$9.2	$8.2
2030	351	$9.2	$8.2	$0.1	$17.5	$9.3	$8.2
2031	354	$9.3	$8.3	$0.1	$17.7	$9.4	$8.3
2032	357	$9.4	$8.3	$0.1	$17.8	$9.4	$8.4
2033	360	$9.5	$8.4	$0.1	$18.0	$9.5	$8.5
2034	364	$9.5	$8.5	$0.1	$18.2	$9.6	$8.5
2035	367	$9.6	$8.6	$0.1	$18.3	$9.7	$8.6
2036	370	$9.7	$8.6	$0.1	$18.5	$9.8	$8.7
2037	374	$9.8	$8.7	$0.1	$18.6	$9.9	$8.8
2038	377	$9.9	$8.8	$0.1	$18.8	$10.0	$8.9
2039	380	$10.0	$8.9	$0.1	$19.0	$10.0	$8.9
2040	384	$10.1	$8.9	$0.1	$19.2	$10.1	$9.0
NPV at 7%		$54.4	$48.3	$0.8	$103.5	$54.7	$48.7
NPV at 3%		$119.3	$106.1	$1.7	$227.1	$120.2	$106.9

Table 5-33 Annual C1 Marine (>600 kW/805 hp) Engine Variable Costs including Recreational Marine >2000 kW; New Tier 4 Engines Only ($Millions)

Calendar Year	Sales	DPF	SCR	Marinization	Total	PM	NO_X+ NMHC
2006		$ -	$ -	$ -	$ -	$ -	$ -
2007		$ -	$ -	$ -	$ -	$ -	$ -
2008		$ -	$ -	$ -	$ -	$ -	$ -
2009		$ -	$ -	$ -	$ -	$ -	$ -
2010		$ -	$ -	$ -	$ -	$ -	$ -
2011		$ -	$ -	$ -	$ -	$ -	$ -
2012	1127	$ -	$ -	$ -	$ -	$ -	$ -
2013	1140	$ -	$ -	$ -	$ -	$ -	$ -
2014	1154	$ -	$ -	$ -	$ -	$ -	$ -
2015	1167	$ -	$ -	$ -	$ -	$ -	$ -
2016	1180	$11.4	$11.1	$0.2	$22.8	$11.5	$11.2
2017	1194	$11.6	$11.3	$0.2	$23.0	$11.7	$11.4
2018	1207	$8.9	$8.7	$0.2	$17.8	$9.0	$8.8
2019	1221	$9.0	$8.8	$0.2	$18.0	$9.1	$8.9
2020	1234	$9.1	$8.9	$0.2	$18.2	$9.2	$9.0
2021	1248	$9.2	$9.0	$0.2	$18.4	$9.3	$9.1
2022	1262	$9.3	$9.1	$0.2	$18.6	$9.4	$9.2
2023	1276	$9.4	$9.2	$0.2	$18.8	$9.5	$9.3
2024	1290	$9.5	$9.3	$0.2	$19.0	$9.6	$9.4
2025	1304	$9.6	$9.4	$0.2	$19.2	$9.7	$9.5
2026	1318	$9.7	$9.5	$0.2	$19.4	$9.8	$9.6
2027	1332	$9.9	$9.6	$0.2	$19.7	$10.0	$9.7
2028	1346	$10.0	$9.7	$0.2	$19.9	$10.1	$9.8
2029	1361	$10.1	$9.8	$0.2	$20.1	$10.2	$9.9
2030	1375	$10.2	$9.9	$0.2	$20.3	$10.3	$10.0
2031	1390	$10.3	$10.0	$0.2	$20.5	$10.4	$10.1
2032	1404	$10.4	$10.1	$0.2	$20.7	$10.5	$10.2
2033	1419	$10.5	$10.2	$0.2	$20.9	$10.6	$10.3
2034	1434	$10.6	$10.3	$0.2	$21.2	$10.7	$10.4
2035	1449	$10.7	$10.4	$0.2	$21.4	$10.8	$10.6
2036	1464	$10.8	$10.6	$0.2	$21.6	$10.9	$10.7
2037	1479	$10.9	$10.7	$0.2	$21.8	$11.1	$10.8
2038	1494	$11.1	$10.8	$0.2	$22.0	$11.2	$10.9
2039	1509	$11.2	$10.9	$0.2	$22.3	$11.3	$11.0
2040	1525	$11.3	$11.0	$0.2	$22.5	$11.4	$11.1
NPV at 7%		$59.5	$58.0	$1.2	$118.6	$60.1	$58.6
NPV at 3%		$131.0	$127.7	$2.7	$261.4	$132.3	$129.0

Table 5-34 Total Annual Engine Variable Costs; New Tier 4 Engines Only ($Millions)

Calendar Year	Locomotive	Marine C1	Marine C2	Recreational Marine	Small Marine	Total	PM	NO_X+ NMHC
2006	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2007	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2008	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2009	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2010	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2011	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2012	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2013	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2014	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2015	$31.9	$ -	$ -	$ -	$ -	$31.9	$31.9	$ -
2016	$33.3	$22.8	$20.2	$ -	$ -	$76.3	$55.6	$20.8
2017	$56.3	$23.0	$20.4	$ -	$ -	$99.7	$48.6	$51.1
2018	$57.4	$17.8	$15.7	$ -	$ -	$90.9	$44.0	$46.9
2019	$51.4	$18.0	$15.9	$ -	$ -	$85.3	$44.8	$40.5
2020	$53.1	$18.2	$16.0	$ -	$ -	$87.3	$45.9	$41.4
2021	$54.8	$18.4	$16.2	$ -	$ -	$89.4	$47.0	$42.4
2022	$56.3	$18.6	$16.3	$ -	$ -	$91.2	$48.0	$43.3
2023	$58.7	$18.8	$16.4	$ -	$ -	$94.0	$49.5	$44.5
2024	$59.8	$19.0	$16.6	$ -	$ -	$95.4	$50.2	$45.2
2025	$61.6	$19.2	$16.7	$ -	$ -	$97.6	$51.4	$46.2
2026	$62.8	$19.4	$16.9	$ -	$ -	$99.2	$52.2	$46.9
2027	$64.3	$19.7	$17.0	$ -	$ -	$101.0	$53.2	$47.8
2028	$65.3	$19.9	$17.2	$ -	$ -	$102.4	$53.9	$48.5
2029	$66.2	$20.1	$17.4	$ -	$ -	$103.6	$54.6	$49.0
2030	$66.9	$20.3	$17.5	$ -	$ -	$104.7	$55.2	$49.5
2031	$68.0	$20.5	$17.7	$ -	$ -	$106.1	$55.9	$50.2
2032	$69.0	$20.7	$17.8	$ -	$ -	$107.6	$56.7	$50.9
2033	$70.1	$20.9	$18.0	$ -	$ -	$109.0	$57.5	$51.6
2034	$71.0	$21.2	$18.2	$ -	$ -	$110.3	$58.2	$52.2
2035	$71.4	$21.4	$18.3	$ -	$ -	$111.1	$58.5	$52.5
2036	$69.4	$21.6	$18.5	$ -	$ -	$109.5	$57.7	$51.8
2037	$67.9	$21.8	$18.6	$ -	$ -	$108.4	$57.1	$51.3
2038	$66.3	$22.0	$18.8	$ -	$ -	$107.2	$56.4	$50.7
2039	$64.5	$22.3	$19.0	$ -	$ -	$105.7	$55.6	$50.1
2040	$62.5	$22.5	$19.2	$ -	$ -	$104.2	$54.8	$49.3
NPV at 7%	$363.5	$118.6	$103.5	$ -	$ -	$585.6	$319.9	$265.7
NPV at 3%	$808.0	$261.4	$227.1	$ -	$ -	$1,296.5	$699.6	$596.9

Note: Marine C1 costs include recreational marine >2000 kW.

Table 5-34 shows the net present value of the annual engine variable costs through 2040 as $1.3 billion at a three percent discount rate or $0.6 billion at a seven percent discount rate. These costs are fairly evenly split between NO_x+NMHC and PM with the primary difference between the two being the two year delay in Tier 4 NO_x standards for locomotive engines.

5.3 Equipment-Related Engineering Costs for New Pieces of Equipment

In this section, we present our estimated costs associated with the piece of equipment into which the new engines are placed—i.e., the locomotive itself or the marine vessel itself. In general, we refer generically to equipment rather than specifically to locomotives or vessels. Costs of control to equipment manufacturers include fixed costs (those costs for equipment redesign), and variable costs (for new hardware and increased equipment assembly time).

5.3.1 New Equipment Fixed Engineering Costs

5.3.1.1 New Equipment Redesign Costs

The projected modifications to equipment resulting from the new emission standards relate to the need to package emission control hardware that engine manufacturers will incorporate into their engines. As discussed above, the additional emission control hardware for equipment into which a Tier 4 engine is installed is proportional in size to engine displacement by roughly a 4:1 ratio (2.5x engine displacement for the SCR system and 1.7x engine displacement for the DPF system). We expect that equipment manufacturers will have to redesign their equipment to accommodate this new volume of hardware. As such, we would expect such costs for only those pieces of equipment that will be installing a Tier 4 engine since Tier 3 engines are expected to incorporate controls that will not result in a larger engine or otherwise require any more space within the piece of equipment.

To determine marine-related redesign costs, our first step was to determine the number of vessels sold each year. Unfortunately, we do not have good data regarding vessel sales. We do have good data regarding engine sales using the PSR database for 2002. To estimate vessel sales, we looked first at the number of engines being sold as marine engines. Since only C2 engines and C1 engines >600 kW (805 hp), including those recreational marine engines >2000 kW, would be complying with the Tier 4 standards, we limited ourselves to those engines. Further, we eliminated those engines sold as auxiliary engines since we know that there exists a direct correlation between vessel sales and propulsion engine sales because every new vessel will have at least one propulsion engine while having anywhere from zero to many auxiliary engines. In the year 2015—one year before vessels would be adding engines equipped with aftertreatment devices and, hence, being redesigned—this leaves us with 993 marine C1 propulsion engines >600 kw and 147 marine C2 propulsion engines.

We know that most vessels in the larger C1 and the C2 categories are fitted with more than one engine. To remain conservative, we estimated that, on average, each new vessel is fitted with 1.5 new propulsion engines. This results in an estimated 660 marine C1 and 100 marine C2 vessels sold.

We believe that not every vessel will require a full redesign. Instead, we believe that, while some vessels truly are a one-design/one-vessel effort, many vessels are a one-design/five-vessel or even ten or more-vessel effort. To be conservative, we have estimated that a redesign effort will accommodate two new vessels. That is, on average, a fleet of 100 new C2 vessels would require 50 redesign efforts. We have estimated the costs per redesign at $50,000 for C1 vessel redesigns and $100,000 for C2 vessel redesigns. These estimates are summarized in Table 5-35.

Table 5-35 Estimated Vessel Redesigns in Year One and Costs per Redesign

	Hp Range	Propulsion Engines in 2015	Engines / Vessel	Vessels	Vessels / Redesign	Redesigns	$/Redesign
Marine-C1 propulsion	>800hp	993	1.5	660	2	330	$50,000
Marine-C2 propulsion	All	147	1.5	100	2	50	$100,000
Total		1140		760		380	

Using these estimates, we can estimate the annual total costs associated with vessel redesigns. But first it is important to note that we do not believe that the C1 and C2 fleets will require these redesign efforts every year. Nor will the need to redesign vessels cease once the Tier 4 standards are implemented. Instead, in the second year of implementation we would expect vessel sales to be similar but in many ways different than in year one. Such is the nature of the marine fleet in contrast to say, the automotive fleet where a new vehicle design is typically carried-over for four to six years with no significant redesign. Nonetheless, a first year redesign effort will no doubt make a second year redesign effort less costly given what was learned by redesign and construction firms during the first year. To estimate this effect, we considered year two to require half the effort of year one, year three half again, and year four half again. We then carried this effort forward until we had accumulated at least 1,000 redesigns which, we believe, is sufficient to have fully redesigned the applicable fleet. The number of marine redesign efforts and the annual total costs are shown in Table 5-36.

Table 5-36 Estimated Total Number of Vessel Redesigns and the Associated Annual Costs; New Tier 4 Equipment only (monetary entries are in $Millions)

Calendar Year	C1 Redesigns	C2 Redesigns	Annual Total Redesigns	Cumulative Redesigns	C1 Redesign Costs	C2 Redesign Costs	Annual Total Costs	PM	NO_X+NMHC
2006	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2007	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2008	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2009	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2010	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2011	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2012	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2013	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2014	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2015	330	50	380	380	$16.5	$5.0	$21.5	$10.8	$10.8
2016	170	30	200	580	$8.5	$3.0	$11.5	$5.8	$5.8
2017	90	20	110	690	$4.5	$2.0	$6.5	$3.3	$3.3
2018	50	10	60	750	$2.5	$1.0	$3.5	$1.8	$1.8
2019	50	10	60	810	$2.5	$1.0	$3.5	$1.8	$1.8
2020	50	10	60	870	$2.5	$1.0	$3.5	$1.8	$1.8
2021	50	10	60	930	$2.5	$1.0	$3.5	$1.8	$1.8
2022	50	10	60	990	$2.5	$1.0	$3.5	$1.8	$1.8
2023	50	10	60	1050	$2.5	$1.0	$3.5	$1.8	$1.8
2024	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2025	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2026	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2027	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2028	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2029	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2030	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2031	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2032	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2033	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2034	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2035	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2036	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2037	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2038	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2039	-	-	-	-	$ -	$ -	$ -	$ -	$ -
2040	-	-	-	-	$ -	$ -	$ -	$ -	$ -
Total						$16.0	$60.5	$30.3	$30.3
NPV at 7%						$7.0	$26.7	$13.3	$13.3
NPV at 3%						$11.1	$42.2	$21.1	$21.1

$44.5
$19.7
$31.1

For locomotive redesign efforts, we believe that the cost per redesign should be roughly equivalent to that for a C2 marine vessel, or $100,000 dollars per redesign, since the engine sizes and corresponding aftertreatment sizes should be roughly the same. Unlike the marine industry, the locomotive industry generally sells many of units of the same design. In fact, we estimate that there are only seven locomotive models—two line haul and five switcher—that comprise the hundreds of locomotives sold each year. Therefore, we have estimated that one redesign effort per model will suffice. The number of locomotive redesign efforts and the annual total costs are shown in

Table 5-37 Estimated Total Number of Locomotive Redesigns and the Associated Annual Costs; New Tier 4 Equipment only (monetary entries are in $Millions)

Calendar Year	Line haul Redesigns	Switcher Redesigns	Line haul Redesign Costs	Switcher Redesign Costs	Annual Total Costs	PM	NO_X+ NMHC
2006	-	-	$ -	$ -	$ -	$ -	$ -
2007	-	-	$ -	$ -	$ -	$ -	$ -
2008	-	-	$ -	$ -	$ -	$ -	$ -
2009	-	-	$ -	$ -	$ -	$ -	$ -
2010	-	-	$ -	$ -	$ -	$ -	$ -
2011	-	-	$ -	$ -	$ -	$ -	$ -
2012	-	-	$ -	$ -	$ -	$ -	$ -
2013	-	-	$ -	$ -	$ -	$ -	$ -
2014	2	5	$0.2	$0.5	$0.7	$0.4	$0.4
2015	-	-	$ -	$ -	$ -	$ -	$ -
2016	-	-	$ -	$ -	$ -	$ -	$ -
2017	-	-	$ -	$ -	$ -	$ -	$ -
2018	-	-	$ -	$ -	$ -	$ -	$ -
2019	-	-	$ -	$ -	$ -	$ -	$ -
2020	-	-	$ -	$ -	$ -	$ -	$ -
2021	-	-	$ -	$ -	$ -	$ -	$ -
2022	-	-	$ -	$ -	$ -	$ -	$ -
2023	-	-	$ -	$ -	$ -	$ -	$ -
2024	-	-	$ -	$ -	$ -	$ -	$ -
2025	-	-	$ -	$ -	$ -	$ -	$ -
2026	-	-	$ -	$ -	$ -	$ -	$ -
2027	-	-	$ -	$ -	$ -	$ -	$ -
2028	-	-	$ -	$ -	$ -	$ -	$ -
2029	-	-	$ -	$ -	$ -	$ -	$ -
2030	-	-	$ -	$ -	$ -	$ -	$ -
2031	-	-	$ -	$ -	$ -	$ -	$ -
2032	-	-	$ -	$ -	$ -	$ -	$ -
2033	-	-	$ -	$ -	$ -	$ -	$ -
2034	-	-	$ -	$ -	$ -	$ -	$ -
2035	-	-	$ -	$ -	$ -	$ -	$ -
2036	-	-	$ -	$ -	$ -	$ -	$ -
2037	-	-	$ -	$ -	$ -	$ -	$ -
2038	-	-	$ -	$ -	$ -	$ -	$ -
2039	-	-	$ -	$ -	$ -	$ -	$ -
2040	-	-	$ -	$ -	$ -	$ -	$ -
Total			$0.2	$0.5	$0.7	$0.4	$0.4
NPV at 7%			$0.1	$0.3	$0.4	$0.2	$0.2
NPV at 3%			$0.2	$0.4	$0.5	$0.3	$0.3

The net present value of the vessel redesign costs are estimated at $42 million using a three percent discount rate and at $27 million using a seven percent discount rate. The net present value of the locomotive redesign costs are estimated at $0.5 million using a three percent discount rate and at $0.4 million using a seven percent discount rate. In total, the net present value of the equipment redesign costs are estimated at $43 million using a three percent discount rate and at $27 million using a seven percent discount rate. These equipment redesign costs are arbitrarily split evenly between NO_x+NMHC and PM control.

5.3.2 New Equipment Variable Engineering Costs

As discussed above, we are projecting that SCR systems and DPFs will be the most likely technologies used to comply with the Tier 4 standards. Upon installation in a new locomotive or a new marine vessel, these devices would require some new equipment related hardware in the form of brackets and/or new sheet metal. Based on engineering judgement, we estimated this cost as shown in Table 5-38. Since the equipment variable costs are linked closely with the size of aftertreatment devices being installed (i.e., the large the diesel engine being installed in the piece of equipment, the larger the aftertreatment devices and, therefore, the larger the necessary brackets and/or greater the necessary sheet metal), it makes sense to scale the equipment hardware costs accordingly. Note that these costs would be incurred by only those pieces of equipment required to comply with the Tier 4 standards.

Table 5-38 Estimated Variable Costs per Piece of New Equipment

	$/new equipment
Locomotive Line-haul	$4,000
Locomotive Switcher	$4,000
Marine C1 (600-1492 kW; 805-2000 hp)	$2,000
Marine C1 (>2000 kW)	$4,000
Marine C1 (sales weighted)	$2,700
Marine C2 (600-1492 kW; 805-2000 hp)	$2,000
Marine C2 (>2000 kW)	$4,000
Marine C2 (sales weighted)	$3,500

Using these costs and estimated future sales of locomotives and vessels, we can estimate the annual costs for the fleet. These costs are shown in Table 5-39, in which we have used the sales weighted costs shown in Table 5-38 for marine vessels. As shown, we estimate the net present value of annual equipment variable costs at $99 million using a three percent discount rate and $44 million using a seven percent discount rate. These costs are arbitrarily split evenly between NO_x+NMHC and PM control.

Table 5-39 Annual Equipment Variable Costs; New Tier 4 Equipment Only ($Millions)

Calendar Year	Line Haul		Switchers		Locomotive Subtotal	Marine C1		Marine C2		Marine Subtotal	Total	PM	NO_X+ NMHC
	Sales	Costs	Sales	Costs		Vessels	Costs	Vessels	Costs				
2006		$ -		$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2007		$ -		$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2008		$ -		$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2009		$ -		$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2010		$ -		$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2011		$ -		$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2012	767	$ -	92	$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2013	765	$ -	92	$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2014	780	$ -	93	$ -	$ -		$ -		$ -	$ -	$ -	$ -	$ -
2015	816	$3.3	93	$0.4	$3.6		$ -		$ -	$ -	$3.6	$1.8	$1.8
2016	854	$3.4	94	$0.4	$3.8	666	$1.8	101	$0.4	$2.2	$6.0	$3.0	$3.0
2017	877	$3.5	94	$0.4	$3.9	672	$1.8	102	$0.4	$2.2	$6.1	$3.0	$3.0
2018	894	$3.6	94	$0.4	$4.0	678	$1.8	103	$0.4	$2.2	$6.2	$3.1	$3.1
2019	917	$3.7	94	$0.4	$4.0	684	$1.9	104	$0.4	$2.2	$6.3	$3.1	$3.1
2020	948	$3.8	94	$0.4	$4.2	690	$1.9	105	$0.4	$2.2	$6.4	$3.2	$3.2
2021	979	$3.9	94	$0.4	$4.3	696	$1.9	106	$0.4	$2.3	$6.6	$3.3	$3.3
2022	1007	$4.0	95	$0.4	$4.4	703	$1.9	106	$0.4	$2.3	$6.7	$3.3	$3.3
2023	1034	$4.1	160	$0.6	$4.8	709	$1.9	107	$0.4	$2.3	$7.1	$3.5	$3.5
2024	1048	$4.2	183	$0.7	$4.9	715	$1.9	108	$0.4	$2.3	$7.2	$3.6	$3.6
2025	1078	$4.3	201	$0.8	$5.1	722	$2.0	109	$0.4	$2.3	$7.5	$3.7	$3.7
2026	1096	$4.4	212	$0.8	$5.2	728	$2.0	110	$0.4	$2.4	$7.6	$3.8	$3.8
2027	1119	$4.5	227	$0.9	$5.4	735	$2.0	111	$0.4	$2.4	$7.8	$3.9	$3.9
2028	1136	$4.5	239	$1.0	$5.5	742	$2.0	112	$0.4	$2.4	$7.9	$4.0	$4.0
2029	1150	$4.6	247	$1.0	$5.6	748	$2.0	113	$0.4	$2.4	$8.0	$4.0	$4.0
2030	1158	$4.6	263	$1.1	$5.7	755	$2.0	114	$0.4	$2.5	$8.1	$4.1	$4.1
2031	1173	$4.7	281	$1.1	$5.8	762	$2.1	115	$0.4	$2.5	$8.3	$4.1	$4.1
2032	1190	$4.8	292	$1.2	$5.9	769	$2.1	116	$0.4	$2.5	$8.4	$4.2	$4.2
2033	1209	$4.8	296	$1.2	$6.0	776	$2.1	118	$0.4	$2.5	$8.5	$4.3	$4.3
2034	1223	$4.9	305	$1.2	$6.1	782	$2.1	119	$0.4	$2.5	$8.7	$4.3	$4.3
2035	1231	$4.9	302	$1.2	$6.1	790	$2.1	120	$0.4	$2.6	$8.7	$4.3	$4.3
2036	1197	$4.8	294	$1.2	$6.0	797	$2.2	121	$0.4	$2.6	$8.5	$4.3	$4.3
2037	1172	$4.7	287	$1.1	$5.8	804	$2.2	122	$0.4	$2.6	$8.4	$4.2	$4.2
2038	1144	$4.6	278	$1.1	$5.7	811	$2.2	123	$0.4	$2.6	$8.3	$4.2	$4.2
2039	1112	$4.4	269	$1.1	$5.5	818	$2.2	124	$0.4	$2.7	$8.2	$4.1	$4.1
2040	1078	$4.3	263	$1.1	$5.4	826	$2.2	125	$0.4	$2.7	$8.0	$4.0	$4.0
NPV at 7%		$26.1		$4.3	$30.4		$11.6		$2.3	$13.9	$44.3	$22.1	$22.1
NPV at 3%		$57.4		$10.3	$67.7		$25.8		$5.1	$30.9	$98.6	$49.3	$49.3

5.4 Operating Costs for New and Remanufactured Engines

We anticipate an increase in costs associated with operating locomotives and marine vessels. We anticipate three sources of increased operating costs: urea use; DPF maintenance; and a fuel consumption impact. Increased operating costs associated with urea use would occur only in those locomotives/vessels equipped with a urea SCR engine. Maintenance costs associated with the DPF (for periodic cleaning of accumulated ash resulting from unburned material that accumulates in the DPF) would occur in those locomotives/vessels that are equipped with a DPF engine. The fuel consumption impact is anticipated to occur more broadly—we expect that a one percent fuel consumption increase would occur for all new Tier 4 locomotive and marine engines due to higher exhaust backpressure resulting from aftertreatment devices. We also expect a one percent fuel consumption increase would occur for remanufactured Tier 0 locomotives due to our expectation that the tighter NO_x standard may in part be met using retarded fuel injection timing.

5.4.1 Increased Operating Costs Associated with Urea Use

New Tier 4 engines are expected to be equipped with urea SCR systems. The costs associated with the urea SCR system, including the urea tank and urea dosing system, are discussed in section 5.2.2.1 of this chapter. To estimate the costs associated with urea use, we first considered the urea dosage rate. For this analysis, we have used a urea dosing rate of four percent urea to every gallon of fuel burned. Using our marine and locomotive emissions analysis work (see Chapter 3 of this draft RIA), we can determine the gallons of fuel burned every year by SCR equipped pieces of equipment. The amount of urea used each year is then four percent of those gallons.

The cost per gallon of urea would be dependent on the volume of urea dispensed at each facility, with smaller refueling sites experiencing higher costs. The type of urea storage/dispensing equipment, and the ultimate cost-per-gallon, for railroad and marine industries will depend on the volume of fuel and urea dispensed at each site. High-volume fixed sites may choose to mix emissions-grade dry urea (or urea liquor) and de-mineralized water on-site, whereas others may choose bulk or container delivery of a pre-mixed 32.5 percent urea-water solution. In 2015, one source suggests that urea cost is expected to be ~$0.75/gallon for retail facilities dispensing 200,000 - 1,000,000 gallons/month, and ~$1.00/gallon for those dispensing 80,000 - 200,000 gallons/month.[25] With the implementation of SCR for the on-highway truck fleet in 2010, the economic factors for each urea supply option will be well-known prior to implementation of the 2016 and 2017 NO_x standards for marine engines and locomotives, respectively. To remain conservative, for this analysis we have used a urea cost of $1.00/gallon. This cost should cover the costs associated with distributing urea to the necessary point of transfer to locomotive and/or vessel (i.e., the necessary infrastructure). The resultant increased operating costs associated with urea use are presented in section 5.4.4. The costs associated with urea use are attributed solely to NO_x+NMHC control.

5.4.2 Increased Operating Costs Associated with DPF Maintenance

The maintenance demands associated with the addition of DPF hardware are discussed in Chapter 4 of this draft RIA. For this analysis, we have estimated a maintenance interval of 200,000 gallons of fuel burned between DPF ash maintenance events. For a typical locomotive engine having ~4000 hp this equates to roughly 7000 hours of operation between maintenance events. By comparison, our NRT4 rule estimated a maintenance interval of 3,000 hours for engines under 175 hp and 4,500 hours for engines over 750 hp. We believe that the estimate of nearly 7,000 hours for the size engines used in applicable marine vessels and locomotives is appropriate, especially given potential use of “pass-through” DPF technologies as discussed in Chapter 4 of this draft RIA. We have also estimated the ash maintenance event to take four hours per event at $50 per hour for labor, or $200 per event.

By using only those gallons burned in DPF equipped engines, we are then able to calculate the maintenance costs associated with DPF maintenance. These costs are presented in section 5.4.4. The costs associated with DPF maintenance are attributed solely to PM control.

5.4.3 Increased Operating Costs Associated with Fuel Consumption Impacts

The high efficiency emission-control technologies expected to be used to meet the proposed Tier 4 standards involve wholly new system components integrated into engine designs and calibrations and, as such, would 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 the integration of the engine and exhaust emission-control systems into a single synergistic emission-control system will lead to locomotive and marine engines that 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 time frame for when this improvement would be realized, we have included this impact in our cost estimates for the full period of the program to avoid underestimating costs.

Diesel particulate filters are anticipated to provide a step-wise decrease in PM emissions by trapping and oxidizing the 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. This approach, called a wall flow filter, results in filtering efficiencies for diesel PM greater than 90 percent but requires additional pumping work to force the exhaust through 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 typically cannot 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. In our NRT4 rule, for wall flow filters, we estimated that the average impact of this increased pumping work was equivalent to an increased fuel consumption of approximately one percent. To be conservative in this analysis, we have used this one percent impact regardless of DPF technology even though the pass through technology that may be used is expected to have a lower impact on fuel consumption because it results in less pumping work to force the exhaust through the device.

As for the urea SCR system, we do not expect a fuel consumption increase associated with this device. Urea SCR catalysts are flow through devices and while they do indeed represent a slight increase in backpressure (i.e., increased pumping work to force exhaust through the device), we expect that impact to be easily offset through engine control changes that take advantage of the high NO_x conversion afforded by the SCR system. Therefore, in total, we expect a one percent fuel consumption increase for all new Tier 4 engines.

We have also estimated an incremental operating cost associated with the locomotive remanufacturing program (see section 5.5 of this chapter for our analysis of other costs associated with the locomotive remanufacturing program). We expect a fuel consumption impact would occur for those engines remanufactured to a more stringent NO_x standard than the NO_x standard to which they were designed originally. We would expect this because those engines are expected to employ engine control changes—retarded injection timing—to help control NO_x emissions. The result of such a change is slightly higher fuel consumption on the order of one percent. Only Tier 0 locomotives would be remanufactured to a more stringent NO_x standard than that for which they were originally designed. Therefore, we have estimated a one percent fuel consumption increase for remanufactured Tier 0 locomotives.

Using the gallons burned in new DPF equipped engines and, for line-haul and passenger locomotives, the gallons burned in remanufactured Tier 0 engines, along with an estimated diesel fuel price less taxes of $1.28/gallon, the costs associated with a fuel consumption impact can be calculated.[j] These costs are presented in section

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[j] To estimate the diesel fuel price, we started with the annual average nationwide price for 2004 for high sulfur diesel fuel (excluding taxes) sold to commercial consumers from Table 41 of the Energy Information Administration (EIA) Petroleum Marketing Annual 2004. We adjusted this 2004 price of $1.24/gallon to a 2012 price using the ratio of projected consumer purchased diesel fuel price in 2012 to the consumer purchased diesel fuel price in 2004 as reported in Table 12 of the Annual Energy Outlook (AEO) 2006. Note that the Petroleum Marketing Annual 2005 shows a corresponding

5.4.4 of this chapter. The costs associated with the fuel consumption impact are split evenly between NO_x and PM control.

5.4.4 Total Increased Operating Costs

The increased annual operating costs for each applicable market segment—locomotive line haul; switcher/passenger; non-recreational marine C1>600 kW; marine C2—are presented in Table 5-40, Table 5-41, Table 5-42, and Table 5-43, respectively. These costs are summarized to give the total increased operating costs in Table 5-44. Table 5-45 shows the increased operating costs by cost element—urea, DPF maintenance, and fuel consumption impact.

Note that operating costs are attributed as follows: costs associated with urea use are attributed solely to NO_x+NMHC control; costs associated with DPF maintenance are attributed solely to PM control; and, costs associated with the fuel consumption impact are split evenly between NO_x+NMHC and PM control.

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nationwide average price for 2005 of $1.80/gallon versus $1.24/gallon. However, the AEO 2007 was not released in time to update our estimated 2012 price using on the $1.80/gallon number. Were we to simply use the $1.80/gallon number, it would increase our 2030 costs from $605 million to $646 million, or roughly seven percent. For the final rule, we will update the fuel price to ensure that we are using the most recent data available.

Table 5-40 Estimated Increased Operating Costs for Line Haul Locomotives; New Tier 4 and Remanufactured Tier 0 and Tier 4 Engines

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Urea Usage (MM gal)	Annual Urea Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	Reman Tier 0 Fuel Usage (MM gal)	New Tier 4 Fuel Usage (MM gal)	Increased Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Costs ($MM)
2006	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
2008	0	0	$0.0	0	0	$0.0	147	0	1	$1.9	$1.9
2009	0	0	$0.0	0	0	$0.0	145	0	1	$1.9	$1.9
2010	0	0	$0.0	0	0	$0.0	375	0	4	$4.8	$4.8
2011	0	0	$0.0	0	0	$0.0	778	0	8	$10.0	$10.0
2012	0	0	$0.0	0	0	$0.0	945	0	9	$12.1	$12.1
2013	0	0	$0.0	0	0	$0.0	1174	0	12	$15.0	$15.0
2014	0	0	$0.0	0	0	$0.0	1227	0	12	$15.7	$15.7
2015	0	0	$0.0	202	1009	$0.2	1232	202	14	$18.4	$18.6
2016	0	0	$0.0	413	2065	$0.4	1400	413	18	$23.2	$23.6
2017	217	9	$8.7	630	3149	$0.6	1553	630	22	$27.9	$37.2
2018	438	18	$17.5	851	4255	$0.9	1511	851	24	$30.2	$48.6
2019	665	27	$26.6	1078	5389	$1.1	1444	1078	25	$32.3	$59.9
2020	899	36	$36.0	1312	6561	$1.3	1335	1312	26	$33.9	$71.2
2021	1141	46	$45.7	1554	7771	$1.6	1219	1554	28	$35.5	$82.7
2022	1390	56	$55.6	1803	9017	$1.8	1108	1803	29	$37.3	$94.7
2023	1853	74	$74.1	2059	10296	$2.1	1002	2059	31	$39.2	$115.3
2024	2314	93	$92.6	2314	11572	$2.3	901	2314	32	$41.2	$136.0
2025	2573	103	$102.9	2573	12866	$2.6	804	2573	34	$43.2	$148.7
2026	2832	113	$113.3	2832	14162	$2.8	710	2832	35	$45.3	$161.5
2027	3093	124	$123.7	3093	15467	$3.1	622	3093	37	$47.6	$174.4
2028	3354	134	$134.2	3354	16770	$3.4	539	3354	39	$49.8	$187.3
2029	3614	145	$144.6	3614	18069	$3.6	462	3614	41	$52.2	$200.3
2030	3871	155	$154.8	3871	19355	$3.9	393	3871	43	$54.6	$213.3
2031	4127	165	$165.1	4127	20637	$4.1	330	4127	45	$57.1	$226.3
2032	4383	175	$175.3	4383	21916	$4.4	273	4383	47	$59.6	$239.3
2033	4639	186	$185.5	4639	23193	$4.6	221	4639	49	$62.2	$252.4
2034	4893	196	$195.7	4893	24464	$4.9	168	4893	51	$64.8	$265.4
2035	5144	206	$205.7	5144	25718	$5.1	124	5144	53	$67.4	$278.3
2036	5383	215	$215.3	5383	26917	$5.4	88	5383	55	$70.0	$290.7
2037	5614	225	$224.6	5614	28072	$5.6	58	5614	57	$72.6	$302.8
2038	5837	233	$233.5	5837	29184	$5.8	33	5837	59	$75.1	$314.5
2039	6050	242	$242.0	6050	30250	$6.0	16	6050	61	$77.6	$325.7
2040	6253	250	$250.1	6253	31267	$6.3	5	6253	63	$80.1	$336.5
NPV at 7%			$546.3			$15.0				$305.5	$866.7
NPV at 3%			$1,455.8			$38.6				$681.7	$2,176.2

Table 5-41Estimated Increased Operating Costs for New Tier 4 Switcher & Passenger Locomotives and Remanufactured Tier 0 and Tier 4 Passenger Locomotives

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Urea Usage (MM gal)	Annual Urea Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	Reman Tier 0 Passenger Fuel Usage (MM gal)	New Tier 4 Passenger Fuel Usage (MM gal)	Increased Passenger Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Costs ($MM)
2006	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
2008	0	0	$0.0	0	0	$0.0	5	0	0	$0.1	$0.1
2009	0	0	$0.0	0	0	$0.0	17	0	0	$0.2	$0.2
2010	0	0	$0.0	0	0	$0.0	29	0	0	$0.4	$0.4
2011	0	0	$0.0	0	0	$0.0	40	0	0	$0.5	$0.5
2012	0	0	$0.0	0	0	$0.0	44	0	0	$0.6	$0.6
2013	0	0	$0.0	0	0	$0.0	48	0	0	$0.6	$0.6
2014	0	0	$0.0	0	0	$0.0	51	0	1	$0.7	$0.7
2015	0	0	$0.0	10	51	$0.0	47	7	1	$0.7	$0.7
2016	0	0	$0.0	21	104	$0.0	49	14	1	$0.8	$0.8
2017	17	1	$0.7	31	156	$0.0	49	22	1	$0.9	$1.6
2018	27	1	$1.1	42	209	$0.0	44	29	1	$0.9	$2.1
2019	38	2	$1.5	53	263	$0.1	38	36	1	$1.0	$2.5
2020	49	2	$2.0	63	317	$0.1	33	44	1	$1.0	$3.0
2021	60	2	$2.4	74	371	$0.1	28	51	1	$1.0	$3.5
2022	78	3	$3.1	85	426	$0.1	22	58	1	$1.0	$4.2
2023	101	4	$4.0	101	505	$0.1	17	66	1	$1.1	$5.2
2024	119	5	$4.8	119	594	$0.1	14	73	1	$1.1	$6.0
2025	138	6	$5.5	138	691	$0.1	10	80	1	$1.2	$6.8
2026	159	6	$6.3	159	793	$0.2	7	88	1	$1.2	$7.7
2027	180	7	$7.2	180	902	$0.2	4	95	1	$1.3	$8.7
2028	203	8	$8.1	203	1016	$0.2	3	102	1	$1.3	$9.7
2029	227	9	$9.1	227	1137	$0.2	1	109	1	$1.4	$10.7
2030	253	10	$10.1	253	1265	$0.3	0	116	1	$1.5	$11.9
2031	281	11	$11.2	281	1404	$0.3	0	123	1	$1.6	$13.1
2032	310	12	$12.4	310	1549	$0.3	0	131	1	$1.7	$14.4
2033	340	14	$13.6	340	1699	$0.3	0	138	1	$1.8	$15.7
2034	371	15	$14.8	371	1856	$0.4	0	146	1	$1.9	$17.1
2035	403	16	$16.1	403	2014	$0.4	0	154	2	$2.0	$18.5
2036	434	17	$17.4	434	2170	$0.4	0	161	2	$2.1	$19.9
2037	464	19	$18.6	464	2322	$0.5	0	168	2	$2.1	$21.2
2038	494	20	$19.8	494	2472	$0.5	0	173	2	$2.2	$22.5
2039	524	21	$20.9	524	2619	$0.5	0	178	2	$2.3	$23.8
2040	553	22	$22.1	553	2764	$0.6	0	183	2	$2.3	$25.0
NPV at 7%			$37.1			$1.0				$9.6	$47.7
NPV at 3%			$102.4			$2.6				$20.6	$125.7

Table 5-42 Estimated Increased Operating Costs for Marine C1 Engines >600 kW, including Recreational Marine >2000 kW; New Tier 4 Engines

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Urea Usage (MM gal)	Annual Urea Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	New Tier 4 Fuel Usage (MM gal)	Increased Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Cost ($MM)
2006	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
2008	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
2010	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	$0.0	$0.0
2012	0	0	$0.0	0	0	$0.0	0	0	$0.0	$0.0
2013	0	0	$0.0	0	0	$0.0	0	0	$0.0	$0.0
2014	0	0	$0.0	0	0	$0.0	0	0	$0.0	$0.0
2015	0	0	$0.0	0	0	$0.0	0	0	$0.0	$0.0
2016	55	2	$2.2	55	275	$0.1	55	1	$0.7	$3.0
2017	150	6	$6.0	150	752	$0.2	150	2	$1.9	$8.1
2018	283	11	$11.3	283	1413	$0.3	283	3	$3.6	$15.2
2019	414	17	$16.6	414	2072	$0.4	414	4	$5.3	$22.3
2020	545	22	$21.8	545	2727	$0.5	545	5	$7.0	$29.3
2021	676	27	$27.0	676	3378	$0.7	676	7	$8.6	$36.3
2022	805	32	$32.2	805	4024	$0.8	805	8	$10.3	$43.3
2023	933	37	$37.3	933	4664	$0.9	933	9	$11.9	$50.2
2024	1059	42	$42.4	1059	5295	$1.1	1059	11	$13.6	$57.0
2025	1183	47	$47.3	1183	5917	$1.2	1183	12	$15.1	$63.7
2026	1305	52	$52.2	1305	6527	$1.3	1305	13	$16.7	$70.2
2027	1424	57	$57.0	1424	7121	$1.4	1424	14	$18.2	$76.6
2028	1539	62	$61.5	1539	7693	$1.5	1539	15	$19.7	$82.8
2029	1639	66	$65.6	1639	8196	$1.6	1639	16	$21.0	$88.2
2030	1719	69	$68.8	1719	8597	$1.7	1719	17	$22.0	$92.5
2031	1782	71	$71.3	1782	8912	$1.8	1782	18	$22.8	$95.9
2032	1835	73	$73.4	1835	9174	$1.8	1835	18	$23.5	$98.7
2033	1882	75	$75.3	1882	9412	$1.9	1882	19	$24.1	$101.3
2034	1925	77	$77.0	1925	9627	$1.9	1925	19	$24.6	$103.6
2035	1964	79	$78.6	1964	9819	$2.0	1964	20	$25.1	$105.7
2036	1999	80	$79.9	1999	9993	$2.0	1999	20	$25.6	$107.5
2037	2030	81	$81.2	2030	10152	$2.0	2030	20	$26.0	$109.2
2038	2060	82	$82.4	2060	10300	$2.1	2060	21	$26.4	$110.8
2039	2087	83	$83.5	2087	10437	$2.1	2087	21	$26.7	$112.3
2040	2113	85	$84.5	2113	10566	$2.1	2113	21	$27.0	$113.7
NPV at 7%			$241.9			$6.0			$77.4	$325.4
NPV at 3%			$620.4			$15.5			$198.5	$834.4

Table 5-43 Estimated Increased Operating Costs for Marine C2 Engines; New Tier 4 Engines

Calendar Year	SCR Equipped Fuel Usage (MM gal)	Urea Usage (MM gal)	Annual Urea Cost ($MM)	DPF Equipped Fuel Usage (MM gal)	# of DPF Maintenance Events/Year	Annual DPF Maintenance Cost ($MM)	New Tier 4 Fuel Usage (MM gal)	Increased Fuel Consumption at 1 percent (MM gal)	Annual Cost of Fuel Consumption Impact ($MM)	Annual Increased Operating Cost ($MM)
2006	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
2008	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
2010	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	$0.0	$0.0
2012	0	0	$0.0	0	0	$0.0	0	0	$0.0	$0.0
2013	0	0	$0.0	0	0	$0.0	0	0	$0.0	$0.0
2014	55	2	$2.2	55	276	$0.1	55	1	$0.7	$3.0
2015	110	4	$4.4	110	552	$0.1	110	1	$1.4	$5.9
2016	213	9	$8.5	213	1063	$0.2	213	2	$2.7	$11.4
2017	317	13	$12.7	317	1585	$0.3	317	3	$4.1	$17.0
2018	422	17	$16.9	422	2108	$0.4	422	4	$5.4	$22.7
2019	526	21	$21.1	526	2632	$0.5	526	5	$6.7	$28.3
2020	631	25	$25.2	631	3155	$0.6	631	6	$8.1	$33.9
2021	735	29	$29.4	735	3677	$0.7	735	7	$9.4	$39.6
2022	840	34	$33.6	840	4199	$0.8	840	8	$10.7	$45.2
2023	944	38	$37.8	944	4719	$0.9	944	9	$12.1	$50.8
2024	1048	42	$41.9	1048	5238	$1.0	1048	10	$13.4	$56.4
2025	1151	46	$46.0	1151	5756	$1.2	1151	12	$14.7	$61.9
2026	1255	50	$50.2	1255	6274	$1.3	1255	13	$16.1	$67.5
2027	1358	54	$54.3	1358	6791	$1.4	1358	14	$17.4	$73.1
2028	1461	58	$58.5	1461	7307	$1.5	1461	15	$18.7	$78.6
2029	1564	63	$62.6	1564	7820	$1.6	1564	16	$20.0	$84.1
2030	1666	67	$66.6	1666	8331	$1.7	1666	17	$21.3	$89.6
2031	1767	71	$70.7	1767	8836	$1.8	1767	18	$22.6	$95.1
2032	1868	75	$74.7	1868	9339	$1.9	1868	19	$23.9	$100.5
2033	1967	79	$78.7	1967	9833	$2.0	1967	20	$25.2	$105.8
2034	2064	83	$82.6	2064	10321	$2.1	2064	21	$26.4	$111.1
2035	2160	86	$86.4	2160	10800	$2.2	2160	22	$27.6	$116.2
2036	2253	90	$90.1	2253	11263	$2.3	2253	23	$28.8	$121.2
2037	2335	93	$93.4	2335	11675	$2.3	2335	23	$29.9	$125.6
2038	2407	96	$96.3	2407	12033	$2.4	2407	24	$30.8	$129.5
2039	2468	99	$98.7	2468	12339	$2.5	2468	25	$31.6	$132.8
2040	2520	101	$100.8	2520	12598	$2.5	2520	25	$32.3	$135.6
NPV at 7%			$264.4			$6.6			$84.6	$355.7
NPV at 3%			$671.4			$16.8			$214.8	$903.0

Table 5-44 Estimated Increased Operating Costs by Market Segment Associated with the Proposal ($Millions)

Calendar Year	Locomotive Line-haul	Locomotive Switcher & Passenger	Marine C1 >600kW	Marine C2	Total	PM	NO_X+ NMHC
2006	$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
2008	$1.9	$0.1	$0.0	$0.0	$1.9	$1.0	$1.0
2009	$1.9	$0.2	$0.0	$0.0	$2.1	$1.0	$1.0
2010	$4.8	$0.4	$0.0	$0.0	$5.2	$2.6	$2.6
2011	$10.0	$0.5	$0.0	$0.0	$10.5	$5.2	$5.2
2012	$12.1	$0.6	$0.0	$0.0	$12.7	$6.3	$6.3
2013	$15.0	$0.6	$0.0	$0.0	$15.6	$7.8	$7.8
2014	$15.7	$0.7	$0.0	$3.0	$19.3	$8.6	$10.7
2015	$18.6	$0.7	$0.0	$5.9	$25.2	$10.6	$14.6
2016	$23.6	$0.8	$3.0	$11.4	$38.9	$14.4	$24.4
2017	$37.2	$1.6	$8.1	$17.0	$64.0	$18.5	$45.4
2018	$48.6	$2.1	$15.2	$22.7	$88.6	$21.7	$66.9
2019	$59.9	$2.5	$22.3	$28.3	$113.1	$24.7	$88.4
2020	$71.2	$3.0	$29.3	$33.9	$137.4	$27.5	$109.9
2021	$82.7	$3.5	$36.3	$39.6	$162.1	$30.3	$131.8
2022	$94.7	$4.2	$43.3	$45.2	$187.4	$33.2	$154.2
2023	$115.3	$5.2	$50.2	$50.8	$221.5	$36.2	$185.3
2024	$136.0	$6.0	$57.0	$56.4	$255.4	$39.2	$216.2
2025	$148.7	$6.8	$63.7	$61.9	$281.1	$42.2	$239.0
2026	$161.5	$7.7	$70.2	$67.5	$306.9	$45.2	$261.7
2027	$174.4	$8.7	$76.6	$73.1	$332.7	$48.3	$284.5
2028	$187.3	$9.7	$82.8	$78.6	$358.4	$51.3	$307.1
2029	$200.3	$10.7	$88.2	$84.1	$383.4	$54.3	$329.1
2030	$213.3	$11.9	$92.5	$89.6	$407.3	$57.2	$350.1
2031	$226.3	$13.1	$95.9	$95.1	$430.3	$60.0	$370.4
2032	$239.3	$14.4	$98.7	$100.5	$452.9	$62.7	$390.2
2033	$252.4	$15.7	$101.3	$105.8	$475.2	$65.4	$409.7
2034	$265.4	$17.1	$103.6	$111.1	$497.1	$68.1	$429.0
2035	$278.3	$18.5	$105.7	$116.2	$518.7	$70.8	$447.9
2036	$290.7	$19.9	$107.5	$121.2	$539.3	$73.3	$466.0
2037	$302.8	$21.2	$109.2	$125.6	$558.8	$75.8	$483.1
2038	$314.5	$22.5	$110.8	$129.5	$577.2	$78.1	$499.2
2039	$325.7	$23.8	$112.3	$132.8	$594.5	$80.2	$514.3
2040	$336.5	$25.0	$113.7	$135.6	$610.7	$82.3	$528.4
NPV at 7%	$866.7	$47.7	$325.4	$355.7	$1,595.4	$267.2	$1,328.3
NPV at 3%	$2,176.2	$125.7	$834.4	$903.0	$4,039.3	$631.4	$3,407.9

Table 5-45 Estimated Increased Operating Costs by Cost Element Associated with the Proposal ($Millions)

Calendar Year	Urea Use	DPF Maintenance	Fuel Impact	Total	PM	NO_X+ NMHC
2006	$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
2008	$0.0	$0.0	$1.9	$1.9	$1.0	$1.0
2009	$0.0	$0.0	$2.1	$2.1	$1.0	$1.0
2010	$0.0	$0.0	$5.2	$5.2	$2.6	$2.6
2011	$0.0	$0.0	$10.5	$10.5	$5.2	$5.2
2012	$0.0	$0.0	$12.7	$12.7	$6.3	$6.3
2013	$0.0	$0.0	$15.6	$15.6	$7.8	$7.8
2014	$2.2	$0.1	$17.1	$19.3	$8.6	$10.7
2015	$4.4	$0.3	$20.5	$25.2	$10.6	$14.6
2016	$10.7	$0.7	$27.4	$38.9	$14.4	$24.4
2017	$28.0	$1.1	$34.8	$64.0	$18.5	$45.4
2018	$46.8	$1.6	$40.2	$88.6	$21.7	$66.9
2019	$65.7	$2.1	$45.3	$113.1	$24.7	$88.4
2020	$85.0	$2.6	$49.9	$137.4	$27.5	$109.9
2021	$104.5	$3.0	$54.6	$162.1	$30.3	$131.8
2022	$124.5	$3.5	$59.4	$187.4	$33.2	$154.2
2023	$153.2	$4.0	$64.3	$221.5	$36.2	$185.3
2024	$181.6	$4.5	$69.2	$255.4	$39.2	$216.2
2025	$201.8	$5.0	$74.3	$281.1	$42.2	$239.0
2026	$222.0	$5.6	$79.3	$306.9	$45.2	$261.7
2027	$242.2	$6.1	$84.4	$332.7	$48.3	$284.5
2028	$262.3	$6.6	$89.6	$358.4	$51.3	$307.1
2029	$281.8	$7.0	$94.6	$383.4	$54.3	$329.1
2030	$300.4	$7.5	$99.4	$407.3	$57.2	$350.1
2031	$318.3	$8.0	$104.1	$430.3	$60.0	$370.4
2032	$335.8	$8.4	$108.7	$452.9	$62.7	$390.2
2033	$353.1	$8.8	$113.2	$475.2	$65.4	$409.7
2034	$370.1	$9.3	$117.7	$497.1	$68.1	$429.0
2035	$386.8	$9.7	$122.2	$518.7	$70.8	$447.9
2036	$402.7	$10.1	$126.5	$539.3	$73.3	$466.0
2037	$417.8	$10.4	$130.6	$558.8	$75.8	$483.1
2038	$431.9	$10.8	$134.5	$577.2	$78.1	$499.2
2039	$445.2	$11.1	$138.2	$594.5	$80.2	$514.3
2040	$457.6	$11.4	$141.7	$610.7	$82.3	$528.4
NPV at 7%	$1,089.7	$28.6	$477.1	$1,595.4	$267.2	$1,328.3
NPV at 3%	$2,850.0	$73.5	$1,115.7	$4,039.3	$631.4	$3,407.9

As shown in Table 5-45, the net present value of the annual operating costs is estimated at $4 billion at a three percent discount rate or $1.6 billion at a seven percent discount rate. The primary increased operating cost is associated with urea use which accounts for nearly three quarters of the estimated costs. Since urea use is meant for NO_x+NMHC control, most of the increased operating costs are attributed to NO_x+NMHC control. Of note in these operating cost tables is the annual reduction of gallons consumed by remanufactured Tier 0 locomotives. This is a result of older Tier 0 locomotives slowly being retired from duty and being replaced by new Tier 4 locomotives. This also explains the corresponding increase in gallons consumed by new Tier 4 locomotives. Not shown in the locomotive operating cost tables are gallons consumed by remanufactured Tier 1, 2 and 3 locomotives because we expect no increased operating cost for those locomotives as a result of this proposal (no new aftertreatment devices so no urea nor DPF maintenance costs and no fuel consumption impact). Also, in Table 5-41 where fuel consumption impacts are calculated, we have considered gallons burned by remanufactured and new Tier 4 passenger locomotives but have not included switchers. We have not included switchers because those locomotives are expected to be powered by nonroad Tier 4 engines having better fuel economy than the switcher engines they replace.

5.5 Engineering Hardware Costs Associated with the Locomotive Remanufacturing Program

Our proposal also contains requirements that remanufactured locomotives meet more stringent standards than those to which they were designed originally. Because the standards for those engines are more stringent, they cannot necessarily be remanufactured to their original configuration but must, instead, include some new technology and/or engine controls to ensure compliance with the more stringent standards. The incremental costs associated with those new technologies must be considered as part of this proposal. The remanufacturing process is not a low cost endeavor. However, it is much less costly than purchasing a perfectly new engine. The costs we have estimated for the remanufacturing program are meant to capture the incremental costs associated with remanufacturing as a result of the proposed program.

To summarize the proposed requirements, the existing fleet of locomotives that are currently subject to Tier 0 standards would need to comply with a new Tier 0 PM standard and a new Tier 0 NO_x line-haul standard, except that Tier 0 locomotives that were newly built before 1994 would remain subject to the existing Tier 0 NO_x standards. In general, these new Tier 0 standards would apply when the locomotive is remanufactured as early as January 1, 2008. For locomotives currently subject to Tier 1 and Tier 2 standards, more stringent PM standards would apply at the point of next remanufacture as early as January 1, 2008, but not later than 2010.

To meet the proposed locomotive remanufactured engine standards, we project that engine manufacturers will utilize incremental improvements to existing engine components. In many cases, similar improvements have already been implemented on new locomotives to meet our current new locomotive standards. To meet the lower NO_x standard proposed for Tier 0 locomotives, we expect possible improvements in the fuel system, the turbo charger, and the engine calibration. Such changes are expected to impact fuel consumption as was discussed in section 5.4.3 of this draft RIA. We have estimated the incremental costs associated with the remanufacture of a Tier 0 locomotive to be $33,800 for the first remanufacture and $22,300 for the second one. The lower cost for the second remanufacture is because not all of the new technology would have to be remanufactured during the second effort. We have estimated that first remanufacture would occur through 2016 with the second one occurring after 2016.

To meet the proposed PM standards for the Tier 1 remanufacturing program, we expect that lubricating oil consumption controls will be implemented, along with the ultra low sulfur diesel fuel requirement for locomotive engines (which was previously finalized in our nonroad clean diesel rulemaking). Because of the significant fraction of lubricating oil present in PM from today's locomotives, we believe that existing low-oil-consumption piston ring-pack designs, when used in conjunction with improvements to closed crankcase ventilation systems, will provide significant, near-term PM reductions. We have estimated these costs to be roughly equivalent to the costs associated with the Tier 0 remanufacturing. We have also estimated the first remanufacture would occur through 2016 with the second one occurring after 2016.

To meet the more stringent proposed PM standards for the Tier 2 remanufacturing program, we expect use of improved fuel systems. Based on work previously done for our NRT4 rule, we have estimated the incremental cost of a new fuel system on a line haul locomotive at $11,750 and on a switcher at $8,700. This cost differential exists because the line haul locomotives have larger engines and, hence, larger fuel rails and pumps, etc. We have not estimated an incremental cost associated with a second remanufacture for Tier 2 locomotives because we would not expect the fuel system would need a second remanufacture. We have estimated that the first remanufacture would occur prior to 2020.

We have not estimated any incremental costs for Tier 3 remanufacturing because these locomotives would not meet a remanufactured standard more stringent than their original design. Therefore, while costs would be incurred to remanufacture these engines, those costs would not be different from current remanufacturing kits.

In the case of our proposed locomotive standards, it is worthwhile to note the difference in how we have handled variable costs for the remanufactured Tier 2 engines versus the new Tier 3 standards. In some cases, we believe manufacturers may choose to introduce more modern common rail fuel systems for both their new Tier 3 products and for application to their existing Tier 2 products at the time of remanufacturing. In the case of the new Tier 3 engine, we are projecting no increase in engine variable cost because, for example, we expect the common rail fuel system to be no more expensive (and perhaps cheaper) than the fuel system that would have been used absent our proposed standards. However, we have accounted for these higher costs for the remanufactured Tier 2 engines reflecting the fact that the new fuel system is an incremental cost for the rebuild that would not have occurred absent our proposed standard (because the existing fuel system could be reused at remanufacture absent the new standard).

For Tier 4 remanufacturing, we have estimated that locomotive engines would need a new set of aftertreatment devices and a remanufactured fuel system. We have estimated the aftertreatment device costs at slightly lower than the original equipment costs because we would expect that precious metals would be recycled from the device being removed and replaced. This results in remanufactured DPF and SCR system costs of 60 percent and 94 percent, respectively, relative to the original cost. The 60/94 differential occurs because of the larger amount of precious metals contained in the DPF versus the SCR catalyst which contains only a small amount of precious metal for the DOC function. For the remanufactured fuel system, we have included the costs already mentioned above associated with costs for Tier 2 remanufacturing (i.e., $11,750 or $8,700).

These estimated incremental remanufacturing costs are summarized in Table 5-46.

Table 5-46 Estimated Incremental Costs Associated with the Locomotive Remanufacturing Program ($/remanufacture)

Segment	Tier	1st Remanufacture	2nd Remanufacture
Locomotive Line-haul	Tier 0	$33,800	$22,300
	Tier 1	$33,800	$22,300
	Tier 2	$11,750	$0
	Tier 3	$0	$0
	Tier 4	$66,000	$66,000
Locomotive Switcher/Passenger	Tier 0	$33,800	$22,300
	Tier 1	$33,800	$22,300
	Tier 2	$8,700	$0
	Tier 3	$0	$0
	Tier 4	$21,700	$21,700

Using these per remanufacture costs, we can calculate the total costs associated with the proposed remanufacturing program. These costs are presented in Table 5-47 for line haul and Table 5-48 for switchers and passenger locomotives. See Chapter 3 of this draft RIA for how we determined the rate at which locomotives are remanufactured. The number remanufactured and the calendar years in which they occur are also shown in the tables. As shown, the net present value of the annual remanufacturing costs is estimated at $1.2 billion and $0.6 billion for line haul locomotives at a three percent and seven percent discount rate, respectively. For switchers and passenger locomotives, we have estimated the net present value of the annual costs at $150 million and $85 million at a three and seven percent discount rate, respectively. In total, the proposed remanufacturing program would have a net present value cost of $1.4 billion at a three percent discount rate and $0.7 billion at a seven percent discount rate. Note that, while not shown in Table 5-47 and Table 5-48, the costs associated with the proposed locomotive remanufacturing program are arbitrarily split evenly between NO_x+NMHC and PM control. This split is shown in Table 5-54.

Table 5-47 Estimated Annual Costs Associated with the Remanufacturing Program for Line Haul Locomotives

Calendar Year	Tier 0			Tier 1			Tier 2			Tier 3			Tier 4			Total ($MM)
	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	
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	661	$33,800	$22.3	-		$0.0	-		$0.0	-		$0	-		$0.0	$22.3
2009	-	$33,800	$0.0	803	$33,800	$27.1	-		$0.0	-		$0	-		$0.0	$27.1
2010	1220	$33,800	$41.2	-	$33,800	$0.0	-		$0.0	-		$0	-		$0.0	$41.2
2011	2078	$33,800	$70.2	489	$33,800	$16.5	-		$0.0	-		$0	-		$0.0	$86.8
2012	972	$33,800	$32.8	931	$33,800	$31.5	-		$0.0	-		$0	-		$0.0	$64.3
2013	1310	$33,800	$44.3	-	$33,800	$0.0	719	$11,749	$8.4	-		$0	-		$0.0	$52.7
2014	618	$33,800	$20.9	-	$33,800	$0.0	826	$11,749	$9.7	-		$0	-		$0.0	$30.6
2015	390	$33,800	$13.2	-	$33,800	$0.0	646	$11,749	$7.6	-		$0	-		$0.0	$20.8
2016	1174	$33,800	$39.7	-	$33,800	$0.0	666	$11,749	$7.8	-		$0	-		$0.0	$47.5
2017	1164	$22,300	$26.0	-	$22,300	$0.0	693	$11,749	$8.1	-		$0	-		$0.0	$34.1
2018	1271	$22,300	$28.4	-	$22,300	$0.0	729	$11,749	$8.6	-		$0	-		$0.0	$36.9
2019	231	$22,300	$5.2	803	$22,300	$17.9	751	$11,749	$8.8	-		$0	-		$0.0	$31.9
2020	370	$22,300	$8.2	-	$22,300	$0.0	-	$0	$0.0	767	$0	$0	-		$0.0	$8.2
2021	-	$22,300	$0.0	489	$22,300	$10.9	-	$0	$0.0	765	$0	$0	-		$0.0	$10.9
2022	579	$22,300	$12.9	931	$22,300	$20.8	-	$0	$0.0	780	$0	$0	-		$0.0	$33.7
2023	1103	$22,300	$24.6	-	$22,300	$0.0	719	$0	$0.0	-	$0	$0	816	$66,021	$53.9	$78.5
2024	501	$22,300	$11.2	-	$22,300	$0.0	826	$0	$0.0	-	$0	$0	854	$66,021	$56.4	$67.5
2025	646	$22,300	$14.4	-	$22,300	$0.0	646	$0	$0.0	-	$0	$0	877	$66,021	$57.9	$72.3
2026	-	$22,300	$0.0	-	$22,300	$0.0	666	$0	$0.0	-	$0	$0	894	$66,021	$59.0	$59.0
2027	-	$22,300	$0.0	-	$22,300	$0.0	693	$0	$0.0	-	$0	$0	917	$66,021	$60.6	$60.6
2028	622	$22,300	$13.9	-	$22,300	$0.0	729	$0	$0.0	-	$0	$0	948	$66,021	$62.6	$76.5
2029	610	$22,300	$13.6	-	$22,300	$0.0	751	$0	$0.0	-	$0	$0	979	$66,021	$64.6	$78.2
2030	505	$22,300	$11.3	-	$22,300	$0.0	-	$0	$0.0	767	$0	$0	1007	$66,021	$66.5	$77.8
2031	-	$22,300	$0.0	442	$22,300	$9.8	-	$0	$0.0	765	$0	$0	1034	$66,021	$68.3	$78.1
2032	-	$22,300	$0.0	-	$22,300	$0.0	-	$0	$0.0	780	$0	$0	1048	$66,021	$69.2	$69.2
2033	-	$22,300	$0.0	-	$22,300	$0.0	-	$0	$0.0	-	$0	$0	1894	$66,021	$125.0	$125.0
2034	-	$22,300	$0.0	220	$22,300	$4.9	-	$0	$0.0	-	$0	$0	1950	$66,021	$128.8	$133.7
2035	-	$22,300	$0.0	419	$22,300	$9.3	-	$0	$0.0	-	$0	$0	1996	$66,021	$131.8	$141.1
2036	-	$22,300	$0.0	-	$22,300	$0.0	324	$0	$0.0	-	$0	$0	2030	$66,021	$134.0	$134.0
2037	-	$22,300	$0.0	-	$22,300	$0.0	372	$0	$0.0	-	$0	$0	2067	$66,021	$136.5	$136.5
2038	-	$22,300	$0.0	-	$22,300	$0.0	291	$0	$0.0	-	$0	$0	2106	$66,021	$139.1	$139.1
2039	-	$22,300	$0.0	-	$22,300	$0.0	300	$0	$0.0	-	$0	$0	2152	$66,021	$142.1	$142.1
2040	-	$22,300	$0.0	-	$22,300	$0.0	312	$0	$0.0	-	$0	$0	2197	$66,021	$145.1	$145.1
NPV at 7%			$231.7			$72.1			$28.4			$0			$264.6	$596.8
NPV at 3%			$332.9			$105.2			$42.8			$0			$743.4	$1,224.3

Table 5-48 Estimated Annual Costs Associated with the Remanufacturing Program for Switcher and Passenger Locomotives

Calendar Year	Tier 0/1			Tier 2			Tier 3			Tier 4			Total ($MM)
	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	
2006	-		$0.0	-		$0.0	-		$0	-		$0.0	$0.0
2007	-		$0.0	-		$0.0	-		$0	-		$0.0	$0.0
2008		$33,800	$1.1	-		$0.0	-		$0	-		$0.0	$1.1
2009		$33,800	$2.6	-		$0.0	-		$0	-		$0.0	$2.6
2010	31	$33,800	$10.6	-		$0.0	-		$0	-		$0.0	$10.6
2011	78	$33,800	$10.5	-		$0.0	-		$0	-		$0.0	$10.5
2012	314	$33,800	$10.5	-		$0.0	-		$0	-		$0.0	$10.5
2013	312	$33,800	$10.4	-		$0.0	-		$0	-		$0.0	$10.4
2014	309	$33,800	$10.4	-		$0.0	-		$0	-		$0.0	$10.4
2015	307	$33,800	$9.1		$8,728	$1.0	-		$0	-		$0.0	$10.1
2016	307	$33,800	$9.2		$8,728	$1.3	-		$0	-		$0.0	$10.5
2017	269	$22,300	$6.1	112	$8,728	$0.8	-		$0	-		$0.0	$6.8
2018	271	$22,300	$6.1	154	$8,728	$0.8	-		$0	-		$0.0	$6.9
2019	273	$22,300	$6.2	88	$8,728	$0.8	-		$0	-		$0.0	$6.9
2020	274	$22,300	$6.2	89	$8,728	$0.8	-		$0	-		$0.0	$7.0
2021	276	$22,300	$6.2	90 -	$0	$0.0		$0	$0	-		$0.0	$6.2
2022	278	$22,300	$6.3	91 -	$0	$0.0		$0	$0	-		$0.0	$6.3
2023	279	$22,300	$7.1	-	$0	$0.0	46	$0	$0	-		$0.0	$7.1
2024	281	$22,300	$7.0	-	$0	$0.0	46	$0	$0	-		$0.0	$7.0
2025	318	$22,300	$6.9		$0	$0.0	92	$0	$0		$21,695	$1.0	$7.9
2026	315	$22,300	$5.9		$0	$0.0	92 -	$0	$0		$21,695	$2.0	$8.0
2027	311	$22,300	$5.8	57	$0	$0.0	46 -	$0	$0	47	$21,695	$2.0	$7.8
2028	266	$22,300	$5.6	169	$0	$0.0	-	$0	$0	93	$21,695	$2.0	$7.7
2029	260	$22,300	$5.5	86	$0	$0.0	-	$0	$0	94	$21,695	$2.0	$7.5
2030	253	$22,300	$5.3	88	$0	$0.0	-	$0	$0	94	$21,695	$2.0	$7.3
2031	245	$22,300	$5.0	89	$0	$0.0		$0	$0	94	$21,695	$2.0	$7.1
2032	236	$22,300	$4.2	90 -	$0	$0.0		$0	$0	94	$21,695	$2.0	$6.3
2033	226	$22,300	$4.0	45 -	$0	$0.0	46	$0	$0	94	$21,695	$3.5	$7.4
2034	190	$22,300	$3.7	-	$0	$0.0	46	$0	$0	94	$21,695	$4.0	$7.7
2035	179	$22,300	$3.4		$0	$0.0	92	$0	$0	160	$21,695	$4.4	$7.8
2036	166	$22,300	$3.2		$0	$0.0	92 -	$0	$0	183	$21,695	$4.6	$7.8
2037	154	$22,300	$2.9	57	$0	$0.0	46 -	$0	$0	201	$21,695	$5.0	$7.9
2038	142	$22,300	$2.7	114	$0	$0.0	-	$0	$0	212	$21,695	$5.2	$7.9
2039	132	$22,300	$2.5	46	$0	$0.0	-	$0	$0	230	$21,695	$5.3	$7.9
2040	123	$22,300	$2.3	46	$0	$0.0	-	$0	$0	238	$21,695	$5.7	$8.0
NPV at 7%	114		$75.0	46		$2.4			$0	246		$7.5	$84.9
NPV at 3%	105		$123.9	46		$3.8			$0	263		$22.3	$150.0

5.6 Summary of Proposed Program Engineering Costs

Details of our engine and equipment cost estimates were presented in Sections 5.2 and 5.3. Here we summarize the cost estimates. Section 5.6.1 summarizes the engine-related costs associated with the proposed program. Section 5.6.2 summarizes the equipment-related costs associated with the proposed program. Section 5.6.3 summarizes the operating costs associated with the proposed program for both new and remanufactured engines. Section 5.6.4 summarizes the hardware costs associated with the locomotive remanufacturing program. Section 5.6.5 summarizes all these costs and presents the total estimated costs for the proposed program. Note that all present value costs presented here are 2006 through 2040 numbers (the net present values in 2006 of the stream of costs occurring from 2006 through 2040, expressed in $2005).

5.6.1 New Engine Engineering Costs

5.6.1.1 New Engine Fixed Engineering Costs

Engine fixed costs include costs for engine R&D, tooling, and certification. These costs are discussed in detail in Section 5.2.1. The total estimated engine fixed costs are summarized in Table 5-49. The table also includes net present values using both a three percent and a seven percent discount rate.

Table 5-49 Summary of Engine-Related Fixed Costs for the Proposed Program ($Millions)

	Costs Incurred	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Engine and Emission Control Research	$ 415	$ 341	$ 267
Engine Tooling	$ 41	$ 33	$ 24
Engine Certification	$ 9	$ 7	$ 6
Total Engine Fixed Costs	$ 466	$ 381	$ 297
Total Allocated to PM	$ 162	$ 133	$ 104
Total Allocated to NO_X+NMHC	$ 303	$ 248	$ 193

Note: As explained in the text, we have attributed engine fixed costs to NO_X+NMHC and PM control as follows: engine research costs are split two-thirds to NO_X+NMHC control and one-third to PM control; engine tooling costs are split equally; engine certification costs are split equally except where new standards are implemented in different years (e.g., for Tier 4 locomotive standards).

5.6.1.2 New Engine Variable Engineering Costs

Engine variable, or hardware, costs are discussed in detail in Section 5.2.2. For engine variable costs, we have generated cost estimation equations as a function of engine displacement (see Table 5-27). Using these equations, we have calculated the hardware costs for new engines meeting the proposed standards for each year through 2040. We present those annual engine variable costs in Section 5.2.2. Table 5-50 shows the net present value of those annual costs using a three percent discount rate and a seven percent discount rate.

Table 5-50 Summary of Engine-Related Variable Costs for the Proposed Program ($Millions)

	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Locomotive	$ 808	$ 364
C1 Marine & Recreational Marine >2000 kW	$ 261	$ 119
C2 Marine	$ 227	$ 104
Recreational Marine <2000 kW	$ 0	$ 0
Small Marine	$ 0	$ 0
Total Engine Variable Costs	$ 1,297	$ 586
Total Allocated to PM	$ 700	$ 320
Total Allocated to NO_X+NMHC	$ 597	$ 266

Note: The PM/NO_X+NMHC cost allocations for engine variable costs are as follows: Urea SCR systems including marinization costs on marine applications are attributed 100% to NO_X+NMHC control; and, DPF systems including marinization costs on marine applications are attributed 100% to PM control.

5.6.2 New Equipment Engineering Costs

5.6.2.1 New Equipment Fixed Engineering Costs

Equipment fixed costs are discussed in detail in Section 5.3.1. Table 5-51 shows the estimated equipment fixed costs—for redesign efforts—associated with the proposed program. The table also includes net present values of the annual costs using both a three percent and a seven percent discount rate.

Table 5-51 Summary of Equipment-Related Fixed Costs for the Proposed Program ($Millions)

	Costs Incurred	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Locomotive	$ 0.7	$ 0.5	$ 0.4
C1 Marine & Recreational Marine >2000 kW	$ 45	$ 31	$ 20
C2 Marine	$ 16	$ 11	$ 7
Recreational Marine <2000 kW	$ 0	$ 0	$ 0
Small Marine	$ 0	$ 0	$ 0
Total Equipment Fixed Costs	$ 61	$ 43	$ 27
Total Allocated to PM	$ 31	$ 21	$ 14
Total Allocated to NO_X+NMHC	$ 31	$ 21	$ 14

Note: Equipment fixed costs are arbitrarily split evenly between NO_X+NMHC and PM control.

5.6.2.2 New Equipment Variable Engineering Costs

Equipment variable costs are discussed in detail in Section 5.3.2. Using the costs presented there we have calculated the hardware costs for new pieces of equipment—locomotives and vessels—meeting the proposed standards for each year through 2040. We present those annual equipment variable costs in Section 5.3.2. Table 5-52 shows the net present value of those annual costs using a three percent and a seven percent discount rate.

Table 5-52 Summary of Equipment-Related Variable Costs for the Proposed Program ($Millions)

	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Locomotive	$ 68	$ 30
C1 Marine & Recreational Marine >2000 kW	$ 26	$ 12
C2 Marine	$ 5	$ 2
Recreational Marine <2000 kW	$ 0	$ 0
Small Marine	$ 0	$ 0
Total Equipment Variable Costs	$ 99	$ 44
Total Allocated to PM	$ 50	$ 22
Total Allocated to NO_X+NMHC	$ 50	$ 22

Note: Equipment variable costs are arbitrarily split evenly between NO_X+NMHC and PM control.

5.6.3 Operating Costs for New and Remanufactured Engines

Operating costs are discussed in detail in Section 5.4 where we present the operating costs for each year through 2040. Operating costs consist of costs associated with urea use, DPF maintenance, and a fuel consumption impact on some engines. Table 5-53 shows the net present value of those annual operating costs using a three percent and a seven percent discount rate.

Table 5-53 Summary of Operating Costs for the Proposed Program ($Millions)

	2006-2040 NPV at 3%				2006-2040 NPV at 7%			
	Urea	DPF Maint.	Fuel	Total	Urea	DPF Maint.	Fuel	Total
Locomotive	$1,558	$41	$702	$2,302	$583	$16	$315	$914
C1 Marine	$620	$16	$199	$834	$242	$6	$77	$325
C2 Marine	$671	$17	$215	$903	$264	$7	$85	$356
Recreational Marine	$ 0	$0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Small Marine	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
Total Operating Costs	$2,850	$74	$1,116	$4,039	$1,090	$29	$477	$1,595

Total Allocated to PM	$ 0	$74	$558	$631	$ 0	$29	$239	$267
Total Allocated to NO_X+NMHC	$2,850	$ 0	$558	$3,408	$1,090	$ 0	$239	$1,328

Note: Operating costs are attributed as follows: costs associated with urea use are attributed solely to NO_X+NMHC control; costs associated with DPF maintenance are attributed solely to PM control; and, costs associated with the fuel consumption impact are split evenly between NO_X+NMHC and PM control.

5.6.4 Remanufacturing Program Engineering Hardware Costs

Costs associated with the locomotive remanufacturing program are discussed in detail in Section 5.5 where we present the costs for each year through 2040. These costs include the hardware costs that are incremental to current remanufacturing practices. Table 5-54 shows the net present value of those annual remanufacturing costs using a three percent and a seven percent discount rate.

Table 5-54 Summary of Locomotive Remanufacturing Program Hardware Costs ($Millions)

	2006-2040 NPV at 3%	2006-2040 NPV at 7%
Line Haul	$ 1,224	$ 597
Switcher & Passenger	$ 150	$ 85
Total Remanufacturing Costs	$ 1,374	$ 682
Total Allocated to PM	$ 687	$ 341
Total Allocated to NO_X+NMHC	$ 687	$ 341

Note: Costs associated with the proposed locomotive remanufacturing program are arbitrarily split evenly between NO_X+NMHC and PM control.

5.6.5 Total Engineering Costs Associated with the Proposed Program

Table 5-55 shows the total annual costs for each market segment—locomotive line haul, C2 marine, etc—for the proposed program. Table 5-56 shows the total annual costs for each cost element—engine, equipment, operating, etc.—on an annual basis for the proposed program. As shown, the net present value of the annual costs is estimated at $7.2 billion at a three percent discount rate and $3.2 billion at a seven percent discount rate. In the year 2030, the annual costs are estimated at $605 million.

Note that costs throughout this analysis have been allocated as follows: engine research costs are split two-thirds to NO_x+NMHC control and one-third to PM control; engine tooling costs are split equally; engine certification costs are split equally except where new standards are implemented in different years (e.g., for Tier 4 locomotive standards); urea SCR systems including marinization costs on marine applications are attributed 100% to NO_x+NMHC control; DPF systems including marinization costs on marine applications are attributed 100% to PM control; equipment fixed and variable costs are arbitrarily split evenly between NO_x+NMHC and PM control; costs associated with urea use are attributed solely to NO_x+NMHC control; costs associated with DPF maintenance are attributed solely to PM control; costs associated with the fuel consumption impact are split evenly between NO_x+NMHC and PM control; and, costs associated with the locomotive remanufacturing program are arbitrarily split evenly between NO_x+NMHC and PM control.

Table 5-55 Estimated Annual Engineering Costs by Market Segment for the Proposed Program ($Millions)

Calendar Year	Locomotive		Marine					Total
	Line Haul	Switcher & Passenger	C2 Marine	C1 Marine >600kW	C1 Marine <600kW	Recreational Marine	Small Marine	
2006	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2007	$0.6	$2.6	$4.2	$2.3	$10.9	$5.8	$1.7	$28.2
2008	$24.9	$3.7	$4.2	$2.3	$10.9	$5.8	$1.7	$53.5
2009	$29.6	$5.4	$4.2	$2.3	$10.9	$5.8	$1.7	$60.0
2010	$48.4	$15.9	$4.2	$2.3	$10.9	$5.8	$1.7	$89.3
2011	$100.6	$18.0	$27.7	$29.4	$16.2	$10.9	$3.7	$206.5
2012	$81.5	$18.2	$20.7	$21.8	$0.0	$0.0	$0.0	$142.2
2013	$72.9	$18.2	$20.7	$21.8	$0.0	$0.0	$0.0	$133.5
2014	$53.7	$21.2	$23.7	$21.8	$0.0	$0.0	$0.0	$120.4
2015	$77.0	$16.9	$40.8	$46.5	$0.0	$0.0	$0.0	$181.2
2016	$112.5	$20.0	$35.0	$36.0	$0.0	$0.0	$0.0	$203.5
2017	$129.7	$10.2	$39.8	$37.4	$0.0	$0.0	$0.0	$217.2
2018	$145.0	$10.8	$39.8	$37.4	$0.0	$0.0	$0.0	$232.9
2019	$145.7	$11.1	$45.6	$44.7	$0.0	$0.0	$0.0	$247.0
2020	$135.0	$11.6	$51.3	$51.9	$0.0	$0.0	$0.0	$249.9
2021	$151.0	$11.4	$57.1	$59.2	$0.0	$0.0	$0.0	$278.6
2022	$187.4	$12.2	$62.9	$66.3	$0.0	$0.0	$0.0	$328.8
2023	$254.5	$15.1	$68.6	$73.4	$0.0	$0.0	$0.0	$411.6
2024	$265.0	$16.2	$73.3	$77.9	$0.0	$0.0	$0.0	$432.6
2025	$284.2	$18.3	$79.1	$84.9	$0.0	$0.0	$0.0	$466.4
2026	$284.8	$19.4	$84.8	$91.6	$0.0	$0.0	$0.0	$480.7
2027	$300.6	$20.5	$90.5	$98.3	$0.0	$0.0	$0.0	$509.9
2028	$330.4	$21.6	$96.2	$104.7	$0.0	$0.0	$0.0	$552.9
2029	$346.0	$22.6	$101.9	$110.3	$0.0	$0.0	$0.0	$580.8
2030	$359.0	$23.8	$107.6	$114.8	$0.0	$0.0	$0.0	$605.2
2031	$373.2	$25.1	$113.2	$118.5	$0.0	$0.0	$0.0	$630.0
2032	$378.3	$25.8	$118.7	$121.5	$0.0	$0.0	$0.0	$644.3
2033	$448.3	$28.4	$124.2	$124.3	$0.0	$0.0	$0.0	$725.2
2034	$470.8	$30.1	$129.6	$126.9	$0.0	$0.0	$0.0	$757.5
2035	$491.6	$31.6	$134.9	$129.2	$0.0	$0.0	$0.0	$787.3
2036	$495.0	$32.8	$140.1	$131.3	$0.0	$0.0	$0.0	$799.1
2037	$508.0	$34.2	$144.7	$133.2	$0.0	$0.0	$0.0	$820.1
2038	$520.6	$35.3	$148.7	$135.1	$0.0	$0.0	$0.0	$839.7
2039	$533.0	$36.4	$152.2	$136.8	$0.0	$0.0	$0.0	$858.4
2040	$544.8	$37.7	$155.2	$138.4	$0.0	$0.0	$0.0	$876.0
NPV at 7%	$1,859.0	$186.0	$551.4	$555.6	$45.3	$25.7	$8.0	$3,231.1
NPV at 3%	$4,258.3	$366.4	$1,255.8	$1,259.5	$52.9	$30.2	$9.4	$7,232.5

Table 5-56 Estimated Annual Engineering Costs by Cost Element for the Proposed Program ($Millions)

Calendar Year	Engine Costs	Equipment Costs	Loco Reman Costs	Operating Costs	Total	PM	NO_X+NMHC
2006	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2007	$28.2	$0.0	$0.0	$0.0	$28.2	$9.3	$18.9
2008	$28.2	$0.0	$23.4	$1.9	$53.5	$22.0	$31.5
2009	$28.2	$0.0	$29.8	$2.1	$60.0	$25.2	$34.8
2010	$32.2	$0.0	$51.8	$5.2	$89.3	$41.9	$47.4
2011	$98.8	$0.0	$97.3	$10.5	$206.5	$93.3	$113.2
2012	$54.8	$0.0	$74.8	$12.7	$142.2	$61.8	$80.4
2013	$54.8	$0.0	$63.1	$15.6	$133.5	$57.5	$76.1
2014	$59.4	$0.7	$41.0	$19.3	$120.4	$52.1	$68.3
2015	$100.0	$25.1	$30.8	$25.2	$181.2	$93.2	$88.1
2016	$89.2	$17.5	$58.0	$38.9	$203.5	$107.7	$95.8
2017	$99.7	$12.6	$40.9	$64.0	$217.2	$93.9	$123.3
2018	$90.9	$9.7	$43.8	$88.6	$232.9	$92.4	$140.5
2019	$85.3	$9.8	$38.8	$113.1	$247.0	$93.9	$153.2
2020	$87.3	$9.9	$15.2	$137.4	$249.9	$86.0	$163.9
2021	$89.4	$10.1	$17.1	$162.1	$278.6	$90.9	$187.7
2022	$91.2	$10.2	$39.9	$187.4	$328.8	$106.2	$222.5
2023	$94.0	$10.6	$85.6	$221.5	$411.6	$133.7	$277.9
2024	$95.4	$7.2	$74.6	$255.4	$432.6	$130.3	$302.3
2025	$97.6	$7.5	$80.2	$281.1	$466.4	$137.4	$329.0
2026	$99.2	$7.6	$67.0	$306.9	$480.7	$134.7	$345.9
2027	$101.0	$7.8	$68.4	$332.7	$509.9	$139.5	$370.3
2028	$102.4	$7.9	$84.1	$358.4	$552.9	$151.3	$401.6
2029	$103.6	$8.0	$85.7	$383.4	$580.8	$155.8	$425.0
2030	$104.7	$8.1	$85.1	$407.3	$605.2	$159.0	$446.2
2031	$106.1	$8.3	$85.2	$430.3	$630.0	$162.7	$467.3
2032	$107.6	$8.4	$75.5	$452.9	$644.3	$161.4	$483.0
2033	$109.0	$8.5	$132.5	$475.2	$725.2	$193.4	$531.8
2034	$110.3	$8.7	$141.3	$497.1	$757.5	$201.3	$556.2
2035	$111.1	$8.7	$148.9	$518.7	$787.3	$208.1	$579.2
2036	$109.5	$8.5	$141.8	$539.3	$799.1	$206.2	$593.0
2037	$108.4	$8.4	$144.4	$558.8	$820.1	$209.3	$610.8
2038	$107.2	$8.3	$147.0	$577.2	$839.7	$212.2	$627.6
2039	$105.7	$8.2	$150.0	$594.5	$858.4	$215.0	$643.4
2040	$104.2	$8.0	$153.1	$610.7	$876.0	$217.7	$658.3
NPV at 7%	$882.6	$71.4	$681.7	$1,595.4	$3,231.1	$1,067.9	$2,163.2
NPV at 3%	$1,677.7	$141.3	$1,374.4	$4,039.3	$7,232.5	$2,222.1	$5,010.5

5.7 Engineering Costs Associated with a Possible Marine Remanufacturing Program

We are requesting comment on the possibility of requiring a remanufacturing program for commercial marine propulsion engines over 600 kW (805 hp), including those recreational marine engines over 2000 kW. While such a program is not being proposed, we believe it is important to estimate costs associated with such a program so as to better inform commenters. We have estimated these costs in a manner similar to those generated for the proposed locomotive remanufacture program. We have estimated the number of remanufactured engines as being equal to our estimate of sales of marine propulsion engines >600 kW, but shifted by nine years to represent the time passage between original sale and remanufacture. We then multiplied those estimated remanufactured engines by the same Tier 0/1 and Tier 2 costs per remanufacture estimated for locomotives since we would expect a similar or identical remanufacturing kit to be used on marine as locomotive engines.

The estimated annual costs of a possible marine remanufacturing program are presented in Table 5-57. As shown, we have estimated the net present value of the annual costs at $413 million and $275 million at a three percent and seven percent discount rate, respectively. Including a marine remanufacturing program would increase the net present value of the annual costs associated with the proposal from $7.2 billion to $7.6 billion using a three percent discount rate and from $3.2 billion to $3.5 billion using a seven percent discount rate. On an annual basis, including a marine remanufacturing program would increase the costs of the proposed program in 2030 from $605 million to $618 million.

Table 5-57 Estimated Annual Costs Associated with a Possible Remanufacturing Program for Marine Engines >600 kW

Calendar Year	Tier 0/1			Tier 2			Total ($MM)
	Remans	$/reman	Subtotal ($MM)	Remans	$/reman	Subtotal ($MM)	
2006	-		$0.0	-		$0.0	$0.0
2007	-		$0.0	-		$0.0	$0.0
2008	866	$33,800	$29.3	-		$0.0	$29.3
2009	902	$33,800	$30.5	-		$0.0	$30.5
2010	939	$33,800	$31.7	-		$0.0	$31.7
2011	976	$33,800	$33.0	-		$0.0	$33.0
2012	1013	$33,800	$34.2	-		$0.0	$34.2
2013	1025	$33,800	$34.7	-		$0.0	$34.7
2014	1038	$33,800	$35.1	-		$0.0	$35.1
2015	1050	$33,800	$35.5	-		$0.0	$35.5
2016	-	$33,800	$0.0	1063	$11,749	$12.5	$12.5
2017	829	$22,300	$18.5	1076	$11,749	$12.6	$31.1
2018	866	$22,300	$19.3	1088	$11,749	$12.8	$32.1
2019	902	$22,300	$20.1	1101	$11,749	$12.9	$33.1
2020	939	$22,300	$20.9	1114	$11,749	$13.1	$34.0
2021	976	$22,300	$21.8	-	$11,749	$0.0	$21.8
2022	1013	$22,300	$22.6	-	$11,749	$0.0	$22.6
2023	1025	$22,300	$22.9	-	$11,749	$0.0	$22.9
2024	1038	$22,300	$23.1	-	$11,749	$0.0	$23.1
2025	1050	$22,300	$23.4	-	$11,749	$0.0	$23.4
2026	-	$0	$0.0	1063	$11,749	$12.5	$12.5
2027	-	$0	$0.0	1076	$11,749	$12.6	$12.6
2028	-	$0	$0.0	1088	$11,749	$12.8	$12.8
2029	-	$0	$0.0	1101	$11,749	$12.9	$12.9
2030	-	$0	$0.0	1114	$11,749	$13.1	$13.1
2031	-	$0	$0.0	-	$11,749	$0.0	$0.0
2032	-	$0	$0.0	-	$11,749	$0.0	$0.0
2033	-	$0	$0.0	-	$11,749	$0.0	$0.0
2034	-	$0	$0.0	-	$11,749	$0.0	$0.0
2035	-	$0	$0.0	-	$11,749	$0.0	$0.0
2036	-	$0	$0.0	-	$11,749	$0.0	$0.0
2037	-	$0	$0.0	-	$11,749	$0.0	$0.0
2038	-	$0	$0.0	-	$11,749	$0.0	$0.0
2039	-	$0	$0.0	-	$11,749	$0.0	$0.0
2040	-	$0	$0.0	-	$11,749	$0.0	$0.0
NPV at 7%			$235.7			$40.1	$275.9
NPV at 3%			$337.0			$75.9	$413.0

5.8 Engineering Costs and Savings Associated with Idle Reduction Technology

Locomotives idle for many reasons, not all of which can be avoided. The primary reason they idle is to protect their engines. Locomotives use water, not antifreeze to cool their engines because water is much more efficient at removing heat, and therefore, one of the primary reasons they idle is to keep the water from freezing and damaging the engine block. Engineers may also idle a locomotive to maintain critical system parameters: the batteries must maintain a certain charge in order to be able to restart the engine, the air brake system must be kept pressurized, and in some cases the locomotive is left to idle in order to properly cool down after heavy use. It may also be necessary to idle a locomotive to provide and maintain cab comfort for the crew, including heat and air conditioning. Idling locomotives can be found both inside and outside of the switchyard, for example, line-hauls may idle while waiting on sidings for other trains to pass, during crew changes, or while moving (when some locomotives in a consist are not needed to provide power).

There are several technologies currently available to reduce unnecessary locomotive idling or idling emissions. First, shore power systems allow for the locomotive engine to be plugged into a stationary power source to keep the batteries charged, and heat and circulate the water and oil. They range in price from $4,000 - $14,000 depending on the options installed.[k] These systems are most widely used on passenger trains that return to the same location at night, but are not practical for switchers that idle in different locations throughout a switchyard, or for line-hauls that generally stop in many locations outside a switchyard. Second, Low Emission Idle Systems (LEI) made by Energy Conversions Inc. work by alternating the banks of cylinders that fire during idle. LEI runs the engine on half of its cylinders at idle which increases the load on the firing cylinders and causes them to burn fuel more efficiently, however, while this system may reduce some idling emissions it does not eliminate idling. An electronic timer controls the switching, and no operator intervention is required. The cost of the system is approximately $4000, and it can be installed in just two hours.[l] Third, an Auxiliary Power Unit (APU) is an idle reduction technology that reduces unnecessary idling by using a small diesel engine (less than 50 hp) to provide power to run cab accessories, heat and circulate water and oil, and charge the locomotive batteries instead of this work being done by the much larger (2,000-4,000 hp) locomotive engine. There are two main manufacturers of APUs, EcoTrans which makes the K9 APU and Kim Hotstart which makes the Diesel Driven Heating System (DDHS). APUs can provide substantial fuel savings depending primarily on the region in which the locomotive it is installed on operates. The cost of an APU is approximately $25,000 - $35,000.[m] Fourth, a more complex solution is being demonstrated in the Advanced Locomotive Emissions Control Systems (ALECS). It uses emission reduction technology developed for stationary sources to capture the emissions from both stationary and slow moving trains in a railyard. Its cost can be upwards of one million dollars.[n] Fifth, locomotive engines can be replaced with two or three smaller on-highway engines. The on-highway

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[k] Linda Gaines, “Reduction of Impacts from Locomotive Idling”, Center for Transportation Research, Argonne National Laboratory

[l] www.energyconversions.com/lei1.htm

[m] Case Study: Chicago Locomotive Idle Reduction Project, EPA420-R-04-003

[n] Tom Christofk, "Statewide Railyard Agreement" Presentation given at Second Public Meeting 7/13/06 for Placer County Air Pollution Control District
htttp://www.placer.ca.gov/upload/apc/documents/up/up_arb_public_meeting_7_13_06.pdf

engines are referred to as gensets[o] which allow one smaller engine to idle while the others are used when more power is needed. Sixth, a hybrid-electric system has been designed for switch yard purposes only (known as the GreenGoat.)[p]

Finally, one of the most cost effective onboard solutions that can provide idle reduction benefits to both line-haul and switcher locomotives nearly everywhere they operate is an automatic engine stop/start system (AESS). AESS is an electronic control system that reduces idling by shutting down a locomotive engine when it is idling unnecessarily. AESS is a microprocessor technology that operates by continually monitoring certain operating parameters such as: reverser and throttle position, engine coolant and ambient air temperature, battery charge, brake system pressure, and time spent idling. The AESS will shutdown the locomotive engine after a prescribed period of time spent idling, usually fifteen to thirty minutes, if conditions meet a preprogrammed set of values (for example the ambient temperature must be greater than 32ºF, and the water temperature must be greater than 100ºF), and will restart the engine if one of the aforementioned parameters is out of its specified range in order to both protect the locomotive engine and keep it in a ready-to-use state.

AESS is limited in its ability to provide idle reduction in cold weather as it can only monitor the conditions under which the locomotive engine is operating and the condition of the engine itself. An APU can provide further reductions for those locomotives operating in colder climates by actually maintaining the necessary engine parameters, and are part of some Tier 0 certified kits. In fact, EPA demonstrated an APU/AESS combined systems approach in one of its grant projects using a Kim Hotstart DDHS.[q] An AESS alone can provide some fuel savings during the cold winter, but when combined with an APU will achieve considerable fuel savings. Under the proposed program, AESS systems will be required on all newly-built Tier 3 and Tier 4 locomotives, and on all existing locomotives when they are first remanufactured under the revised remanufacturing program (see section III.C.(1)(c) of the Preamble for more details on the idle reduction program).

If installed at the time of remanufacture, the AESS installation costs vary depending on the age and characteristics of the locomotive. On average, the cost of a basic system is approximately $10,000, and in some cases volume discounts may be available.[k,r] This cost estimate includes not only labor costs for installation, but also

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[o] www.northeastdiesel.org, "Multi-Engine GenSet Ultra Low Emissions Road-Switcher Locomotive" presentation by National Railway Equipment Co., Jan, 2006.

[p] www.railpower.com

[q] See "Case Study: Chicago Locomotive Idle Reduction Project" (EPA420-R-04-003) (March, 2004), available at http://www.epa.gov/smartway/documents/420r04003.pdf

[r] Jessica Montañez and Matthew Mahler, "Reducing Idling Locomotives Emissions", North Carolina Department of Environment and Natural Resources, DAQ
http://daq.state.nc.us/planning/locoindex.shtml

the hardware costs for a basic AESS microprocessor system and monitoring equipment (systems including GPS or satellite uplink optional features are more expensive). The cost may also vary depending on whether the locomotive is already equipped with the necessary sensors, and whether the AESS would require a stand alone electronic control unit as may be the case for older locomotives that are completely mechanical and do not have electronic controls. If installed on a new locomotive, costs should be much lower since the equipment could be installed at the factory and integrated with the original design of the locomotive.

Idle reduction technology (e.g., AESS systems) can provide substantial emission reductions as well as cost savings by reducing fuel consumption. We estimated these cost savings for both a line-haul and switcher locomotive using 4,350 annual hours of operation for a line-haul or 36,500 hours over one useful life, and 4,450 annual hours for a switcher or 101,000 hours over one useful life (see section 3.3.2 of this RIA for more details). The regulatory duty cycle (see 40CFR 92.132 for more details) indicates that a line-haul idles for 38% of its operating time, and that a switcher locomotive idles for 59.8% of its operating time. Using these values, we can estimate that a line-haul locomotive idles approximately 1,650 hours annually or nearly 14,000 hours over one useful life, and a switcher locomotive idles approximately 2,660 hours annually or slightly over 60,000 hours over one useful life.

These duty cycles include two types of idling: normal idle and low idle. Low idle indicates that there is no accessory load on the engine where normal idle indicates a load on the engine (for example, an accessory load occurs when the locomotive engine is charging a battery). As a conservative estimate, we are calculating a 50% reduction in low idling, although additional reductions in both low and normal idling may be possible. Using this reduction value, we have estimated that an AESS will reduce unnecessary idling by over 410 hours a year on a line-haul, and approximately 660 hours a year on a switcher. This means that over the useful life a line-haul locomotive, we expect at least 2,900 hours of idling at a 3% net present value (2,500 at 7% net present value) to have been eliminated, and at least 11,000 hours of idling at a 3% net present value (7,400 hours at 7% net present value) over the course of one useful life for a switcher locomotive. Using a fuel consumption value of three gallons per hour from Tier 2 Certification data, and a price of $1.28 for one gallon of diesel fuel and the yearly amount of idle hours avoided, we can estimate that this technology will pay for itself in just under four years on a switcher locomotive, and over one useful life on a line-haul locomotive will return all but $500.00 of the initial investment. It is important to note that locomotives typically operate for more than one useful life, and this technology does not have to be replaced upon remanufacturing the locomotive and therefore, it should continue to provide savings throughout the additional useful lives of the locomotives. It is also important to note that our estimates are conservative when compared to estimates by other groups, and when compared to data from locomotives equipped with AESS in the field. For comparative purposes, Table 5-58 shows the different payback times associated with the different savings estimates. Data from locomotives in the field indicate that payback time may be just slightly over one year, and that figure comes from an average of both line-haul and switcher locomotives that have been collected over many years of operation in many different geographical regions of the country.

Table 5-58 Estimates of Typical AESS Payback Time by other Sources

Source of Estimate	Hours of Idle per switcher locomotive per year	AESS reduced hours of idle	Fuel Usage during idle (gal/hour)	Gallons Saved per Year	Cost of Fuel[b]	Fuel Savings ($)	Payback time of AESS[c]
EPA - Ann Arbor	2,650	665	3[d]	2,000	$1.28	$2,600	3.8 years
DOE	5,300	2,650	4.5	12,000	$1.28	$15,400	8 months
EPA - NE	4,000	1,000	3-11	5,700	$1.28	$7,300	1.4 years
SmartStart Reports	3,840[a]	2,050	4.5	9,200	$1.28	$11,800	10 months

[a] This average value comes from data accumulated over at least three years on both line-haul and switcher locomotives

[b] The $1.28 cost of a gallon of diesel is calculated in Chapter 5 of this RIA

[c] Payback time of AESS is based on average price of $10,000 which includes installation costs

[d] 3 gal/hr is based on Tier 2 Certification Data

For simplicity we are presenting savings and emission reductions for a single useful life, even though locomotives are typically remanufactured at least three times before being scrapped. The AESS hardware would generally be expected to last for the remainder of a locomotive's service life, which could be as little as one useful life for a very old locomotive being remanufactured for the last time to more than four useful lives for a newly manufactured locomotive. Thus actual cost savings will be significantly higher than the single useful life values presented here, even when discounted.

It is also important to note that while we present annual and per-useful life emission reductions here, these reductions are considered as part of the emission reductions from the proposed standards. Under the current and proposed regulations, locomotives are tested and emissions are calculated to reflect the emission reductions associated with idle reduction technologies. AESS systems are currently being used by some manufacturers and remanufacturers as part of their certified locomotive emission controls. From both a regulatory and inventory perspective, the use of AESS is considered the same as installing aftertreatment or recalibrating the engine. The emission reductions are presented here merely to show the environmental significance of AESS.

AESS targets ‘low idle’ operation which occurs when the locomotive is not:

- Maintaining critical system parameters (such as air brake cylinder pressure)
- Propelling the locomotive

- Protecting the engine from freezing
- Providing cabin comfort to its crew.

The AESS is designed to eliminate unnecessary idling which is primarily composed of low idle, and it is estimated that at least half of this low idle can be eliminated using an AESS.[s,t,u] This conservative estimate shows that on a per-locomotive basis, idling of a line-haul locomotive can be reduced by over 400 hours annually or at least 3,500 hours over its useful life using an AESS. For switchers, which spend considerably more time idling because of their function, AESS could reduce idling by over 660 hours annually or by at least 15,000 hours over the useful life of the locomotive.

This reduced idling time means less fuel consumed. Tier 2 certification data indicates that modern locomotives typically burn 3 gallons of fuel an hour during low-idle. We calculated the cost savings of using an AESS based on an estimated diesel fuel price less taxes of $1.28/gallon (see 5.4.3 for more details). For a line-haul locomotive, use of an AESS is estimated to provide fuel cost savings of almost $1,600 annually. Over the useful life, this would mean a net present value savings of nearly $11,000 at a three percent discount rate ($9,500 at a seven percent discount rate). For a switcher locomotive, an AESS could provide fuel savings of nearly $2,500 annually or, over its useful life, a net present value savings of approximately $41,000 at a three percent discount rate ($28,000 at a seven percent discount rate).

Idle reduction would also result in emissions reductions. Tier 2 certification data suggests that locomotives emit an average of 10g/hr of PM and 600g/hr of NO_x during low idle. This means that a line-haul locomotive's emissions could be reduced by over 0.005 tons of PM and 0.27 tons of NO_x annually. Over the useful life, the net present value of PM reductions could be 0.032 tons at a three percent discount rate (0.027 tons at a seven percent discount rate). Likewise, the net present value of NO_x reductions could be 1.9 tons at a three percent discount rate (1.5 tons at a seven percent discount rate). A switcher locomotive's emissions can be reduced by over 0.007 tons of PM and 0.44 tons NO_x annually. Over the useful life of the switcher, the net present value of PM reductions could be 0.12 tons at a three percent discount rate (0.08 tons at a seven percent discount rate) and, for NO_x reductions, 7.0 tons at a three percent discount rate (4.9 tons at a seven percent discount rate), older switchers would be expected to emit more pollutants than the Tier 2 estimates given here.

Table 5-59 shows the annual fuel savings, the associated cost savings, and the emissions reductions we estimate would result from the proposed AESS

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[s] David E. Brann, "Locomotive Idling Reduction" http://www1.eere.energy.gov/vehiclesandfuels/pdfs/idling_2004/brann.pdf

[t] http://www.arb.ca.gov/railyard/ryagreement/aess_electromotive.pdf

[u] Draft Maryland Locomotive Idle Reduction Program Demonstration Project – DE-FG36-02GO12022 http://www.osti.gov/bridge/servlets/purl/838872-D6MxUD/838872.PDF

requirements. These values would be expected to be consistent for newer locomotives, although older locomotives may provide greater savings as they may consume more fuel at idle. Table -5-60 shows this information on a useful life basis along with net present value information and a net cost. The idle emission reductions are particularly important considering that we do not expect aftertreatment technologies to reduce NO_x emissions at idle, and further, we expect PM control to be reduced due to poor oxidation efficiency at idle. The ability of aftertreatment technologies to control emissions during idle operation is discussed in more detail in Chapter 4 of this draft RIA. Because of the limitations of the aftertreatment technology at idle, idle reduction via an AESS system is the best method to ensure control of emissions at idle.

Table 5-59 Annual Effects of Using AESS on Line-Haul and Switcher Locomotives

Annual Estimates for a Typical Tier 2 Locomotive						
Type of Locomotive	Time Spent Idling[a] (hrs)	Idling Reduced Using AESS[b] (hrs)	Fuel Savings[c] (gals)	Fuel Savings[d] ($)	PM Emission Reductions[e] (tons)	NO_x Emission Reductions[f] (tons)
Line-Haul	1,650	413	1,238	1,584	0.005	0.27
Switcher	2,650	663	1,988	2,544	0.007	0.44

a Using 38% idling time for line-hauls and 59.8% for switchers from Duty-Cycle (see 40CFR 92.132)
b Assuming 50% of low-idle is reduced by AESS
c Using 3 gallons of fuel burned per hour at low-idle (estimated from Tier 2 Certification Data)
d Using diesel fuel price less taxes of $1.28/gallon (see section 5.4.3)
e Using PM estimate of 10g/hr emitted during low idle (estimated from Tier 2 Certification Data)
f Using NO_x estimate of 600g/hr emitted during low idle (estimated from Tier 2 Certification Data)

Table -5-60 NPV 3% & 7% Effects of Using AESS Over the First Useful Life on Line-Haul and Switcher Locomotives

Estimates Over the First[a] Useful Life of a Typical Tier 2 Locomotive									
Type of Locomotive	NPV Factor	Time Spent Idling[b] (hrs)	Idling Reduced Using AESS[c] (hrs)	Fuel Savings[d] (gals)	Fuel Savings[e] ($)	Average Installation Cost of AESS($)	Net Savings ($)	PM Emission Reductions[f] (tons)	NO_x Emission Reductions[g] (tons)
Line-Haul	NPV 3%	12,000	2,900	8,700	11,000	10,000	1,000	0.032	1.9
	NPV 7%	9,900	2,500	7,400	9,500	10,000	-500	0.027	1.6
Switcher	NPV 3%	42,000	11,000	32,000	41,000	10,000	29,000	0.12	7.0
	NPV 7%	29,000	7,400	22,000	28,000	10,000	16,000	0.08	4.9

a Additional savings not accounted for in this analysis include: reduced wear on engine components, reduced oil consumption, and fuel savings over subsequent useful lives of a locomotive's full lifetime.
b Using 38% idling time for line-hauls and 59.8% for switchers from Duty-Cycle (see 40CFR 92.132)
c Assuming 50% of low-idle is reduced by AESS

d Using 3 gallons of fuel burned per hour at low-idle (estimated from Tier 2 Certification Data)
e Using diesel fuel price less taxes of $1.28/gallon (see section 5.4.3)
f Using PM estimate of 10g/hr emitted during low idle (estimated from Tier 2 Certification Data)
g Using NO_X estimate of 600g/hr emitted during low idle (estimated from Tier 2 Certification Data)

Note that we have not included the costs and savings associated with AESS systems in the overall cost analysis of the program summarized in Section 5.6. The primary reason for this is the expectation that these systems would be in widespread use absent a requirement from EPA, even in retrofit applications on existing locomotives. We did not believe it would be appropriate to assume no one would employ these systems absent a requirement, nor did we want to assume that everyone would absent a requirement. Further, as shown in Table -5-60, a net savings is likely which would, in effect, reduce the overall cost of our proposed program were we to include the costs and savings associated with AESS systems. Because of the difficulty and uncertainty involved in estimating their use absent a requirement, and their net effect of providing savings to users, we decided to present the costs and savings separately from the overall program.

5.9 Analysis of Energy Effects

Under E.O. 13211, a “significant energy action” is any regulatory action that might have a significant adverse effect on the supply, distribution, or use of energy. A significant adverse effect is, along with several other factors, any outcome that could reduce crude oil supply in excess of 10,000 barrels per day, reduce fuel production in excess of 4,000 barrels per day, or increase energy usage in excess of either of those thresholds. The proposed locomotive and marine program is projected to have an impact on fuel usage in excess of one of these thresholds.

Section 5.4.3 of this draft RIA presents our analysis of the increased costs associated with fuel consumption impacts that would result from both the addition of diesel particulate filters to some locomotive and marine engines, and the remanufacture of Tier 0 locomotive engines. Table 5-40 through Table 5-43 show the increased number of gallons we have estimated would be consumed as a result of the proposed program. Using the metrics of 42 gallons of fuel per barrel of crude oil and 365 days in a year, the projected number of barrels of oil per day can be calculated as shown in Table 5-61. As shown, in the year 2026, our proposed program is projected to result in excess of 4,000 barrels of oil per day in increased energy usage. Note that the fuel consumption estimates shown in Table 5-61 do not reflect the potential fuel savings associated with automatic engine stop/start (AESS) systems or other idle reduction technologies. As discussed in section 5.8, such technologies can provide significant fuel savings which could offset the increased fuel consumption estimates shown in Table 5-61.

Table 5-61 Estimated Increase in Fuel Consumed in Million Gallons per Year and Average Barrels per Day

Calendar Year	Increase in Fuel Consumed (Million gallons per year)			Barrels/day
	Locomotive	Marine	Total	
2006	0	0	0	0
2007	0	0	0	0
2008	2	0	2	99
2009	2	0	2	106
2010	4	0	4	264
2011	8	0	8	534
2012	10	0	10	646
2013	12	0	12	797
2014	13	1	13	870
2015	15	1	16	1043
2016	19	3	21	1399
2017	23	5	27	1775
2018	24	7	31	2047
2019	26	9	35	2307
2020	27	12	39	2544
2021	29	14	43	2781
2022	30	16	46	3025
2023	31	19	50	3275
2024	33	21	54	3528
2025	35	23	58	3785
2026	36	26	62	4043
2027	38	28	66	4303
2028	40	30	70	4564
2029	42	32	74	4820
2030	44	34	78	5066
2031	46	35	81	5304
2032	48	37	85	5538
2033	50	38	88	5771
2034	52	40	92	5999
2035	54	41	95	6227
2036	56	43	99	6447
2037	58	44	102	6657
2038	60	45	105	6856
2039	62	46	108	7044
2040	64	46	111	7224

5.10 Cost Effectiveness

One tool that can be used to assess the value of the proposed program is the costs incurred per ton of emissions reduced. This analysis involves a comparison of our proposed program to other measures that have been or could be implemented. 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 from the current year 2006 through the year 2040. This approach captures all of the costs and emissions reductions from our proposed program including those costs incurred and emissions reductions generated by the locomotive remanufacturing program. The baseline case for this evaluation is the existing set of engine standards for locomotive and marine diesel engines and the existing locomotive remanufacturing requirements. The analysis timeframe 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 new standards.

Table 5-62 shows the emissions reductions associated with the proposed locomotive and marine program. These reductions are discussed in more detail in Chapter 3 of this draft RIA.

Table 5-62 Estimated Emissions Reductions Associated with the Proposed Locomotive and Marine Standards (Short tons)

Year	$PM_{2.5}$	PM_{10} [a]	NO_x	NMHC
2015	7,000	7,000	84,000	14,000
2020	15,000	15,000	293,000	25,000
2030	28,000	29,000	765,000	39,000
2040	38,000	40,000	1,123,000	50,000
NPV at 3%	315,000	325,000	7,869,000	480,000
NPV at 7%	136,000	140,000	3,188,000	216,000

a Note that, $PM_{2.5}$ is estimated to be 97 percent of the more inclusive PM_{10} emission inventory. In Chapter 3 we generate and present $PM_{2.5}$ inventories since recent research has determined that these are of greater health concern. Traditionally, we have used PM_{10} in our cost effectiveness calculations. Since cost effectiveness is a means of comparing control measures to one another, we use PM_{10} in our cost effectiveness calculations for comparisons to past control measures.

Using the costs associated with PM and NO_x control shown in Table 5-56 and the emission reductions shown in Table 5-62, we can calculate the $/ton associated with the proposed program. These are shown in Table 5-63. The resultant cost per ton numbers depend on how the costs are allocated to each pollutant. We have allocated costs as closely as possible to the pollutants for which they are incurred. These allocations are also discussed in detail in Section 5.6 of this draft RIA.

Table 5-63 Proposed Program Aggregate Cost per Ton and Long-Term Annual Cost per Ton

Pollutant	2006 Thru 2040 Discounted Lifetime Cost Per Ton At 3%	2006 Thru 2040 Discounted Lifetime Cost Per Ton At 7%	Long-Term Cost Per Ton In 2030
NO_x+NMHC	$600	$630	$550
PM	$6,840	$7,640	$5,560

The costs per ton shown in Table 5-63 for 2006 through 2040 use the net present value of the annualized costs and emissions reductions associated with the program for the years 2006 through 2040. We have also calculated the costs per ton of emissions reduced in the year 2030 using the annual costs and emissions reductions in that year alone. These numbers are also shown in Table 5-63 and represent the long-term annual costs per ton of emissions reduced.[v] All of the costs per ton include costs and emission reductions that will occur from the locomotive remanufacturing program.

We can also look at the costs, emissions reductions, and cost per ton associated with each of the proposed program elements: the locomotive remanufacturing program; the Tier 3 program; and, the Tier 4 program. We have done this simply by breaking out the costs we have allocated to each of these program elements and the emissions reductions we have allocated to each of these program elements. In other words, we have not done a true incremental analysis that would look at the costs and emissions reductions of, say, the Tier 3 program were it to go on forever, or the Tier 4 program were it done absent of the Tier 3 program. We have looked at program alternatives that would approximate such an analysis and have summarized our findings in Chapter 8 of this draft RIA. There, we look at alternatives that consist of a Tier 3 program that lasts forever but also includes a locomotive remanufacturing program. We have also looked at a Tier 4 program absent any Tier 3 standards but, again, that alternative includes a locomotive remanufacturing program and a different Tier 4 start year. Here, we look simply at the costs and emissions reductions we have allocated to each of our program elements within the context of the entire program. The results are shown in Table 5-64. The table shows costs, reductions, and costs per ton in the year 2030 and as net present values using a three percent discount rate. The results show that the Tier 3 program is the most cost efficient of the program elements, and that all three elements are very cost efficient.

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[v] "Long-term" cost here refers to the ongoing cost of the program where only operating and variable costs remain (no more fixed costs). We have chosen 2030 to represent those costs here.

Table 5-64 Costs, Emissions Reductions, and Cost per Ton Associated with the Proposed Program Elements

	Present Values @ 3%							2030						
Costs ($Millions)	Locomotive		Marine		Loco & Marine		Total	Locomotive		Marine		Loco & Marine		Total
Program Element	PM	NO_X	PM	NO_X	PM	NO_X		PM	NO_X	PM	NO_X	PM	NO_X	
Reman Program (T0,T1,T2)	$401	$401	n/a	n/a	$401	$401	$802	$11	$11	n/a	n/a	$11	$11	$22
Tier 3	$6	$11	$45	$83	$51	$94	$145	$0	$0	$0	$0	$0	$0	$0
Tier 4	$1,180	$2,626	$590	$1,890	$1,770	$4,515	$6,285	$102	$259	$46	$177	$148	$435	$584
Total Cost of Proposal	$1,587	$3,038	$635	$1,973	$2,222	$5,010	$7,233	$113	$270	$46	$177	$159	$446	$605

	Present Values @ 3%						2030					
Reductions (Tons)	Locomotive		Marine		Loco & Marine		Locomotive		Marine		Loco & Marine	
Program Element	PM2.5	NO_X	PM2.5	NO_X	PM2.5	NO_X	PM2.5	NO_X	PM2.5	NO_X	PM2.5	NO_X
Reman Program (T0,T1,T2)	64,020	694,410	n/a	n/a	64,020	694,410	3,010	24,440	n/a	n/a	3,010	24,440
Tier 3	62,420	78,260	82,040	2,135,320	144,460	2,213,580	5,860	7,110	7,960	205,510	13,820	212,620
Tier 4	57,200	3,480,330	49,300	1,489,400	106,500	4,969,730	5,730	369,030	5,170	159,690	10,900	528,720
Total Reductions from Proposal	183,630	4,252,990	131,350	3,624,720	314,980	7,877,710	14,600	400,580	13,120	365,200	27,720	765,780

	Present Values @ 3%						2030					
Cost Effectiveness ($/ton)	Locomotive		Marine		Loco & Marine		Locomotive		Marine		Loco & Marine	
Program Element	PM10	NO_X	PM10	NO_X	PM10	NO_X	PM10	NO_X	PM10	NO_X	PM10	NO_X
Reman Program (T0,T1,T2)	$6,080	$580	n/a	n/a	$6,080	$580	$3,480	$440	n/a	n/a	$3,480	$440
Tier 3	$90	$140	$540	$40	$350	$40	$0	$0	$0	$0	$0	$0
Tier 4	$20,010	$750	$11,600	$1,270	$16,120	$910	$17,340	$700	$8,600	$1,110	$13,200	$820
$/ton of Proposal	$8,380	$714	$4,690	$540	$6,840	$640	$7,520	$670	$3,390	$480	$5,560	$580

Note: Table 5-63 shows $/ton NO_X; there is a slight difference compared to tables showing $/ton NO_X+NMHC.

References for Chapter 5

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[1] "Electronic Systems and EGR Costs for Nonroad Engines," Final Report, ICF Consulting, December, 2002, Public Docket No. A-2001-28, Docket Item II-A-10.
[2] "Aftertreatment Marinizing Costs for CI Engines <30 L/cyl," Final Report, ICF International, September 2006; Docket ID Number EPA-HQ-OAR-2003-0190.
[3] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.
[4] "Update of EPA's Motor Vehicle Emission Control Equipment Retail Price Equivalent (RPE) Calculation Formula," Jack Faucett Associates, Report No. JACKFAU-85-322-3, September 1985, Public Docket No. A-2001-28, Docket Item II-A-74.
[5] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.
[6] "Learning Curves in Manufacturing," Linda Argote and Dennis Epple, Science, February 23, 1990, Vol. 247, pp. 920-924.
[7] Power Systems Research, OELink Sales Version, 2002.
[8] Bureau of Labor Statistics at http://data.bls.gov, Producer Price Index for Total Manufacturing Industries, series ID PCUOMFG--OMFG, shows an annual PPI value for 2005 of 150.8 versus a March 2004 value (publication of the NRT4 rule) of 140.3 for a PPI adjustment of 1.075 (150.8/140.3).
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[10] "Treating Progress Functions As Managerial Opportunity", J.M Dutton and A. Thomas, Academy of Management Review, Rev. 9, 235, 1984, Public Docket A-2001-28, Docket Item II-A-73.
[11] Nonconformance Penalty Final Rule, 67 FR 51464, August 8, 2002.
[12] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.
[13] "Estimated Economic Impact of New Emission Standards for Heavy-Duty On-Highway Engines," March 1997, EPA420-R-97-009, Public Docket A-2001-28, Docket Item II-A-136.
[14] Estimates for Heavy-Duty Gasoline Vehicles," Arcadis Geraghty & Miller, September 1998, EPA Air Docket A-2001-28, Docket Item II-A-77.
[15] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.

[16] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.

[17] Nonconformance Penalty Final Rule, 67 FR 51464, August 8, 2002.

[18] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.
[19] Bureau of Labor Statistics at http://data.bls.gov, Producer Price Index for Total Manufacturing Industries, series ID PCUOMFG--OMFG, shows an annual PPI value for 2005 of 150.8 versus a January 2000 value (publication of the 2007 HD Highway rule) of 130.8 for a PPI adjustment of 1.153 (150.8/130.8).

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[20] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.

[21] Johnson Matthey, www.platinum.matthey.com.

[22] "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999, Public Docket No. A-2001-28, Docket Item II-A-76.

[23] "Aftertreatment Marinizing Costs for CI Engines <30 L/cyl," Final Report, ICF International, September 2006; Docket ID Number EPA-HQ-OAR-2003-0190.

[24] "Aftertreatment Marinizing Costs for CI Engines <30 L/cyl," Final Report, ICF International, September 2006; Docket ID Number EPA-HQ-OAR-2003-0190.

[25] "Viability of Urea Infrastructure for SCR Systems," presented by M.D. Jackson, at the U.S. EPA Clean Diesel Implementation Workshop, August 6, 2003.

CHAPTER 6: COST-BENEFIT ANALYSIS

CHAPTER 6: Cost-Benefit Analysis

6.1 Overview

This chapter presents our analysis of the health and environmental benefits that can be expected to occur as a result of the proposed locomotive and marine engine standards throughout the period from initial implementation through 2030. Nationwide, the engines subject to the proposed emission standards in this rule are a significant source of mobile source air pollution. The proposed standards would reduce exposure to direct $PM_{2.5}$, NO_x and air toxics emissions and help avoid a range of adverse health effects associated with ambient ozone and $PM_{2.5}$ levels.

EPA is required by Executive Order (E.O.) 12866 to estimate the benefits and costs 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 particulate matter (PM) and ozone precursor emission reductions (direct PM and NO_x)? (2) what is the monetary value of the changes in these effects attributable to the proposed rule? and (3) how do the monetized benefits compare to the costs? It constitutes one part of EPA's thorough examination of the relative merits of this regulation.

All of the benefit estimates for the proposed control options in this analysis are based on an analytical structure and sequence similar to that used in the final PM NAAQS analysis.[1] The benefits analysis relies on three major components:

- Calculation of the impact of the proposed rule on the national nonroad emissions inventory of precursors to ozone and $PM_{2.5}$, specifically NO_x, and direct PM, for two future years (2020 and 2030).

- Air quality modeling for 2020 and 2030 to determine changes in ambient concentrations of ozone and $PM_{2.5}$, reflecting baseline and post-control emissions inventories.

- 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 ozone and $PM_{2.5}$ for the modeled standards.

A wide range of human health and welfare effects are linked to the emissions of direct PM and NO_x and the resulting impact on ambient concentrations of ozone and $PM_{2.5}$. Recent studies have linked short-term ozone exposures with premature mortality. Exposure to ozone has also been linked to a variety of respiratory effects including hospital admissions and illnesses resulting in school absences. Potential human health effects associated with $PM_{2.5}$ range from premature mortality to morbidity effects linked to long-term (chronic) and shorter-term (acute) exposures (e.g., respiratory and cardiovascular symptoms resulting in hospital admissions, asthma exacerbations, and acute and chronic bronchitis). Welfare effects potentially linked to PM include materials damage and visibility impacts, while ozone can adversely affect the agricultural and forestry sectors by decreasing yields of crops and forests.

EPA typically quantifies PM- and ozone-related benefits in its regulatory impact analyses (RIAs) when possible. In the analysis of past air quality regulations, ozone-related benefits have included morbidity endpoints and welfare effects such as damage to commercial crops. EPA has not recently included a separate and additive mortality effect for ozone, independent of the effect associated with fine particulate matter. For a number of reasons, including 1) advice from the Science Advisory Board (SAB) Health and Ecological Effects Subcommittee (HEES) that EPA consider the plausibility and viability of including an estimate of premature mortality associated with short-term ozone exposure in its benefits analyses and 2) conclusions regarding the scientific support for such relationships in EPA's 2006 Air Quality Criteria for Ozone and Related Photochemical Oxidants (the CD), EPA is in the process of determining how to appropriately characterize ozone-related mortality benefits within the context of benefits analyses for air quality regulations. As part of this process, we are seeking advice from the National Academy of Sciences (NAS) regarding how the ozone-mortality literature should be used to quantify the reduction in premature mortality due to diminished exposure to ozone, the amount of life expectancy to be added and the monetary value of this increased life expectancy in the context of health benefits analyses associated with regulatory assessments. In addition, the Agency has sought advice on characterizing and communicating the uncertainty associated with each of these aspects in health benefit analyses.

Since the NAS effort is not expected to conclude until 2008, the agency is currently deliberating how best to characterize ozone-related mortality benefits in its rulemaking analyses in the interim. For the analysis of the proposed locomotive and marine standards, we do not quantify an ozone mortality benefit. So that we do not provide an incomplete picture of all of the benefits associated with reductions in emissions of ozone precursors, we have chosen not to include an estimate of total ozone benefits in the proposed RIA. By omitting ozone benefits in this proposal, we acknowledge that this analysis underestimates the benefits associated with the proposed standards. Our analysis, however, indicates that the rule's monetized PM2.5 benefits alone substantially exceed our estimate of the costs.

Table 6.1-1 summarizes the annual monetized health and welfare benefits associated with the proposed standards for two years, 2020 and 2030. There are a number of items to note about these benefits:

- Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used in the air quality and benefits modeling are slightly different than the emission control program being proposed. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Section 3.6 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final proposed regulatory scenario.

- Consistent with the approach used in the recent RIA for the PM NAAQS, rather than presenting both a "primary" estimate of the benefits and a separate characterization of the uncertainty associated with that estimate, the current analysis follows the recommendation of the National Research Council's (NRC) 2002 report "Estimating the Public Health Benefits of Proposed Air Pollution Regulations" to begin moving the assessment of uncertainties from its ancillary analyses into its main benefits presentation through the conduct of probabilistic analyses.

- Since the publication of CAIR, we have completed a full-scale expert elicitation designed to more fully characterize the state of our understanding of the concentration-response function for PM-related premature mortality. Consistent with the approach used in the recent RIA for the PM NAAQS, the elicitation results form a major component of the current effort to use probabilistic assessment techniques to integrate uncertainty into the main benefits analysis.

- Since the publication of CAIR, a follow-up to the Harvard Six-Cities study on premature mortality was published (Laden et al., 2006 based on Dockery et al., 1993),[2,3] which both confirmed the effect size from the first study and provided additional confirmation that reductions in $PM_{2.5}$ directly result in reductions in the risk of premature death. Consistent with the approach used in the recent RIA for the PM NAAQS, we further characterize uncertainty by presenting a range of PM-related premature mortality estimates derived from both the American Cancer Society (ACS) cohort study (Pope et al.,2002),[4] used as the primary estimate of PM-related mortality in previous Regulatory Impact Analyses (RIAs), and the Six-Cities study (Laden et al., 2006).

- Consistent with the approach used in the recent RIA for the PM NAAQS, we have updated our projections of mortality incidence rates to be consistent with the U.S. Census population projections that form the basis of our future population estimates. Compared to the methodology used in the CAIR analysis, this change will result in a reduction in mortality impacts in future years, as overall mortality rates are projected to decline for most age groups.

- Consistent with the approach used in the recent RIA for the PM NAAQS, we provide additional characterizations of the impacts of assuming alternative thresholds in the concentration-response functions derived from the epidemiology literature. Unless specifically noted, our base PM-related premature mortality benefits estimates are based on an assumed cutpoint in the long-term mortality concentration-response function at 10 µg/m3, and an assumed cutpoint in the short-term morbidity concentration-response functions at 10 µg/m3. We also show the results of a sensitivity analysis for PM-related premature mortality, with 4 alternative cutpoints, at 3 µg/m3, 7.5 µg/m3, 12 µg/m3, and 14 µg/m3.

Table 6.1-1. Estimated Monetized PM-Related Health Benefits of the Proposed Locomotive and Marine Engine Standards

	Total Benefits[a,b,c,d] (billions 2005$)	
	2020	2030
PM mortality derived from the ACS cohort study;Morbidity functions from epidemiology literature		
Using a 3% discount rate	$4.4+B	$12+B
Confidence Intervals (5th - 95th %ile)	($1.0 - $10)	($2.1 - $27)
Using a 7% discount rate	$4.0+B	$11+B
Confidence Intervals (5th - 95th %ile)	($1.0 - $9.2)	($1.8 - $25)
PM mortality derived from lower bound and upper bound expert-based result;[e] Morbidity functions from epidemiology literature		
Using a 3% discount rate	$1.7+B - $12+B	$4.6+B - $33+B
Confidence Intervals (5th - 95th %ile)	($0.2 - $8.5) – ($2.0 - $27)	($1.0 - $23) – ($5.4 - $72)
Using a 7% discount rate	$1.6+B - $11+B	$4.3+B - $30+B
Confidence Intervals (5th - 95th %ile)	($0.2 - $7.8) – ($1.8 - $24)	($1.0 - $21) – ($4.9 - $65)

[a] Benefits include avoided cases of mortality, chronic illness, and other morbidity health endpoints.

[b] PM-related mortality benefits estimated using an assumed PM threshold of 10 μg/m3. There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate. For a more detailed discussion of this issue, please refer to Section 6.6.1.3 of the RIA.

[c] 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 6.1-2.

[d] Results reflect the use of two different discount rates: 3 and 7 percent, which are recommended by EPA's Guidelines for Preparing Economic Analyses[5] and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation.

[e] The effect estimates of nine of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by ACS and Six-Cities studies. One of the experts fall below this range and two of the experts are above this range. Although the overall range across experts is summarized in this table, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means. Likewise the 5th and 95th percentiles for these highest and lowest judgments of the effect estimate do not imply any particular distribution within those bounds. The distribution of benefits estimates associated with each of the twelve expert responses can be found in tables 6.4-3 and 6.4-4.

Table 6.1-2 lists the full complement of human health and welfare effects associated with PM, ozone and air toxics, and identifies those effects that are quantified for the primary estimate and those that remain unquantified because of current limitations in methods or available data.

Table 6.1-2. Human Health and Welfare Effects of Pollutants Affected by the Proposed Standards

Pollutant/Effect	Quantified and Monetized in Base Estimates[a]	Unquantified Effects - Changes in:
PM/Health[b]	Premature mortality based on both cohort study estimates and on expert elicitation[c,d] Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Respiratory symptoms (asthmatic population) Infant mortality	Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
PM/Welfare		Visibility in Southeastern Class I areas Visibility in northeastern and Midwestern Class I areas Household soiling Visibility in western U.S. Class I areas Visibility in residential and non-Class I areas UVb exposure (+/-)[e]
Ozone/Health[f]		Premature mortality: short-term exposures Hospital admissions: respiratory Emergency room visits for asthma Minor restricted-activity days School loss days Asthma attacks Cardiovascular emergency room visits Acute respiratory symptoms Chronic respiratory damage Premature aging of the lungs Nonasthma respiratory emergency room visits UVb exposure (+/-)[e]
Ozone/Welfare		Decreased outdoor worker productivity Yields for commercial crops Yields for commercial forests and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[e]
CO Health		Behavioral effects
Nitrogen Deposition/ Welfare		Commercial forests due to acidic sulfate and nitrate deposition Commercial freshwater fishing due to acidic deposition Recreation in terrestrial ecosystems due to acidic deposition Commercial fishing, agriculture, and forests due to

Pollutant/Effect	Quantified and Monetized in Base Estimates[a]	Unquantified Effects - Changes in:
		nitrogen deposition Recreation in estuarine ecosystems due to nitrogen deposition Ecosystem functions Passive fertilization
NO_x/Health		Lung irritation Lowered resistance to respiratory infection Hospital admissions for respiratory and cardiac diseases
HC/Toxics Health[g]		Cancer, including lung (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene) 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 mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) 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 and congestion (acrolein) Neurotoxicity (n-hexane, toluene, xylenes)
HC/Toxics Welfare[g]		Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

[a] Primary quantified and monetized effects are those included when determining the primary estimate of total monetized benefits of the proposed standards.

[b] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[c] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli, 2001 for a discussion of this issue).[6]

[d] While some of the effects of short-term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short-term PM exposure not captured in the cohort estimates included in the primary analysis.

[e] May result in benefits or disbenefits. See Section 6.5.3 for more details.

[f] In addition to primary economic endpoints, there are a number of biological responses that have been associated with ozone health including increased airway responsiveness to stimuli, inflammation in the lung, acute inflammation and respiratory cell damage, and increased susceptibility to respiratory infection. The public health impact of these biological responses may be partly represented by our quantified endpoints.

[g] The categorization of unquantified toxic health and welfare effects is not exhaustive.

The general benefits analysis framework is as follows:

- Given baseline and post-control emissions inventories for the emission species expected to affect ambient air quality, we use sophisticated photochemical air quality models to estimate baseline and post-control ambient concentrations of PM and visibility for each year.

- The estimated changes in ambient concentrations are then combined with monitoring data to estimate population-level potential 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.

- Changes in population exposure to ambient air pollution are then input to impact functions[A] to generate changes in the incidence of health effects, or changes in other exposure metrics are input to dose-response functions to generate changes in welfare effects. Because these estimates contain uncertainty, we characterize the benefits estimates probabilistically when appropriate information is available.

- 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 benefits resulting from the changes in emissions.

EPA is currently developing a comprehensive integrated strategy for characterizing the impact of uncertainty in key elements of the benefits modeling process (e.g., emissions modeling, air quality modeling, health effects incidence estimation, valuation) on the benefits estimates. A recently completed component of this effort is an expert elicitation designed to characterize more fully our understanding of PM-related mortality resulting from both short-term and long-term exposure.[B] We include the results of the formal expert elicitation among the sources of information used in developing health impact functions for this benefits analysis. The results of the 'pilot' for this expert elicitation were presented in RIAs for both the Nonroad Diesel and Clean Air Interstate Rules.[7,8] The results of these elicitation projects, including peer review comments, are available on EPA's Web site, at http://www.epa.gov/ttn/ecas/. In addition,

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[A] The term "impact function" as used here refers to the combination of a) an effect estimate obtained from the epidemiological literature, b) the baseline incidence estimate for the health effect of interest in the modeled population, c) the size of that modeled population, and d) the change in the ambient air pollution metric of interest. These elements are combined in the impact function to generate estimates of changes in incidence of the health effect. The impact function is distinct from the C-R function, which strictly refers to the estimated equation from the epidemiological study relating incidence of the health effect and ambient pollution. We refer to the specific value of the relative risk or estimated coefficients in the epidemiological study as the "effect estimate." In referencing the functions used to generate changes in incidence of health effects for this RIA, we use the term "impact function" rather than C-R function because "impact function" includes all key input parameters used in the incidence calculation.

[B] Expert elicitation is a formal, highly structured and well documented process whereby expert judgments, usually of multiple experts, are obtained (Ayyub, 2002).

similar to our approach in the Nonroad Diesel and CAIR RIAs, we present a distribution of benefits estimates based on a more limited set of uncertainties, those characterized by the sampling error and variability in the underlying health and economic valuation studies used in the benefits modeling framework. We note that incorporating only the uncertainty from random sampling error omits important sources of uncertainty (e.g., in the functional form of the model, as discussed below). Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. Both approaches have different strengths and weaknesses that are summarized later in this chapter.

The benefits estimates generated for the proposed standards are subject to a number of assumptions and uncertainties, which are discussed throughout this document. For example, key assumptions underlying the data-derived concentration-response functions for the $PM_{2.5}$-related 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. Although biological mechanisms for this effect have not yet been specifically identified, the weight of the available epidemiological, toxicological, and experimental evidence supports an assumption of causality. The impacts of including a probabilistic representation of causality are explored using the results of the expert elicitation.
2. All fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because the composition of PM produced via transported precursors emitted from locomotive and marine engines may differ significantly from direct PM released from electric generating units (EGUs) and other industrial sources.[C] In accordance with advice from the CASAC, EPA has determined that no clear scientific grounds exist for supporting differential effects estimates by particle type, based on information in the most recent Criteria Document. We provide a decomposition of benefits by PM component species to provide additional insights into the makeup of the benefits associated with reductions in overall $PM_{2.5}$ mass (See Tables 5-32 and 5-33).
3. The C-R function for fine particles is approximately linear within the range of ambient concentrations under consideration (above the assumed threshold of 10 $\mu g/m^3$). Thus, we assume that the CR functions are applicable to estimates of health benefits associated with reducing fine particles in areas with varied concentrations of PM, including both regions that are in attainment with $PM_{2.5}$ standards and those that do not meet the standards. However, we examine the impact of this assumption by looking at alternative thresholds in a sensitivity analysis.

The first and third of these assumptions are directly addressed in the expert elicitation, providing probabilistic characterizations of the likelihood of causality and the shape of the concentration-response function. The second of these is not directly addressed by the expert

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[C] Even within certain components such as directly emitted PM, there may be significant differences in toxicity of component particles such as trace metals and specific carbonaceous species.

elicitation, and remains a significant source of uncertainty in the state of knowledge about the health benefits associated with various emission reduction strategies.

In addition, a key assumption underlying the entire analysis is that the forecasts for future emissions and associated air quality modeling are valid. Because we are projecting emissions and air quality out to 2030, there are inherent uncertainties in all of the factors that underlie the future state of emissions and air quality levels. While it is important to keep in mind 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 the impacts of this rule.

In addition to the quantified and monetized benefits summarized above, a number of additional categories associated with ozone and $PM_{2.5}$ and its precursor emissions are not currently amenable to quantification or valuation. These include reduced acid and particulate deposition damage to cultural monuments and other materials, 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 ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (i.e., changes in heart rate variability). As a result, monetized benefits generated for the primary estimate may underestimate the total benefits attributable to attainment of alternative standards.

Benefits estimated for this analysis were generated using the Environmental Benefits Mapping and Analysis Program (BenMAP). BenMAP is a computer program developed by EPA that integrates a number of the modeling elements used in previous RIA's (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effect incidence estimates and monetized benefit estimates. Interested parties may wish to consult the webpage http://www.epa.gov/ttn/ecas/benmodels.html for more information.

This chapter is organized as follows. In Section 6.2, we provide an overview of the air quality impacts modeled for the proposed standards that are used as inputs to the benefits analysis. In Section 6.3, we document the key methods and inputs used in the benefits analysis. In Section 6.4, we report the results of the analysis for human health and welfare effects. In Section 6.5, we present a comparison of the costs and benefits associated with the proposed standards.

6.2 Air Quality Impacts for Benefits Analysis

In Chapter 2, we summarize the methods for and results of estimating air quality for the 2020 and 2030 base case and proposed control scenario. These air quality results are in turn associated with human populations and ecosystems to estimate changes in health and welfare effects. For the purposes of the benefits analysis, we focus on the health effects that have been linked to ambient changes in $PM_{2.5}$ related to emission reductions estimated to occur due to the proposed standards. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). The air quality modeling Technical Support Document (TSD), which can be found in the docket for this proposed rule, contains detailed information about the modeling conducted for this rule. In this section, we describe how the modeled air quality results were used for the benefits analysis.

We remind the reader that the emission control scenarios used in the air quality and benefits modeling are slightly different than the emission control program being proposed. The differences reflect further refinements of the regulatory program since we performed the air quality modeling for this rule. Emissions and air quality modeling decisions are made early in the analytical process. Chapter 3.6 of the RIA describes the changes in the inputs and resulting emission inventories between the preliminary assumptions used for the air quality modeling and the final proposed regulatory scenario.

6.2.1 Converting CMAQ Outputs to Full-Season Profiles for Benefits Analysis

This analysis extracted hourly, surface-layer PM concentrations for each grid cell from the standard CMAQ output files. To estimate PM-related health and welfare effects for the contiguous United States, we use model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species 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. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2002 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating EPA speciation network (ESPN) ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 36 km grid.[D]

The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 1999). The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the proposed emissions controls. Full documentation of the revised SMAT methodology is contained in the Air Quality Modeling TSD.

6.2.2 $PM_{2.5}$ Air Quality Results

This section provides a summary of the predicted ambient $PM_{2.5}$ concentrations from the CMAQ model for the 2020 and 2030 base cases and changes associated with the proposed rule. Table 6.2-1 provides those $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure, therefore, better reflects the potential benefits of these predicted changes through exposure changes to these populations.

[D] The 36-km grid squares contain the population data used in the health benefits analysis model, BenMAP.

Table 6.2-1. Summary of CMAQ-Derived Population-Weighted $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Due to the Locomotive and Marine Engine Proposed Standards

	2020	**2030**
Statistic[a]	**Change**[b]	**Change**[b]
$PM_{2.5}$ Metrics: National Population-Weighted Average (ug/m^3)		
Annual Average Concentration	0.05	0.10

[a] $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates based on the results of spatial and temporal Voronoi Neighbor Averaging.

[b] The change is defined as the base-case value minus the control-case value.

[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

6.3 Benefits Analysis – Data and Methods

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 nonoverlapping 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 benefit-cost analyses of environmental quality programs and has been used in several recent published analyses (Banzhaf, Burtraw, and Palmer, 2002; Hubbell et al., 2004; Levy et al., 2001; Levy et al., 1999; Ostro and Chestnut, 1998).

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 PM, a health and welfare impact analysis must first be conducted to convert air quality changes into effects that can be assigned dollar values. Inherent in each of these steps is a high degree of uncertainty, due both to the randomness of environmental factors such as meteorology, and the difficulty in measuring and predicting model inputs such as pollutant emissions. As such, where possible, we incorporate probabilistic representations of model inputs and outputs. However, in many cases, probabilistic representations are not available. In these cases, we use the best available science and models, and characterize uncertainty using sensitivity analyses.

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 $PM_{2.5}$. These impacts may be positive or negative, but in general, for the proposed standards, they 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 examine impacts of changes in visibility. We also provide qualitative discussions of the impact of changes in other environmental and ecological effects, for example, changes in yields for commercial forests and noncommercial crops and 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 to improve the accuracy and robustness of benefits estimates.

6.3.1 Valuation Concepts

In valuing health impacts, we note that reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects by a fairly small amount for a large population. The appropriate economic measure is willingness to pay[E] (WTP) for changes in risk prior to the regulation (Freeman, 2003).[F] Adoption of WTP as the measure of value implies that the value of environmental quality improvements depends 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 the measure of benefits. These cost of illness (COI) estimates generally (although not in every case) understate the true value of reductions in risk of a health effect, because they do not include the value of avoided pain and suffering from the health effect (Harrington and Portney, 1987; Berger et al., 1987).

[E] For many goods, WTP can be observed by examining actual market transactions. For example, if a gallon of bottled drinking water sells for $1, it can be observed that at least some people are willing to pay $1 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., nontoxic cleaners or bike helmets). Alternatively, surveys can be used in an attempt to directly elicit WTP for an environmental improvement.

[F] In general, economists tend to view an individual's WTP for an 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. In some cases, such as the value of fatal risk reductions, we use WTA measures due to the difficulty in obtaining WTP estimates. For cases where the changes in the good are small WTP and WTA are approximately equal.

One distinction in environmental benefits estimation is between use values and nonuse values. Although no general agreement exists among economists on a precise distinction between the two (see Freeman [2003]), the general nature of the difference is clear. Use values are those aspects of environmental quality that affect an individual's welfare 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.

Nonuse 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. Nonuse values are not traded, directly or indirectly, in markets. For this reason, measuring nonuse values has proven to be significantly more difficult than measuring use values. The air quality changes produced by the proposed standards would cause changes in both use and nonuse values, but the monetary benefits 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 cannot be used. There are three main nonmarket valuation methods used to develop values for endpoints considered in this analysis: stated preference (including contingent valuation [CV]), indirect market (e.g., hedonic wage), and avoided cost methods.

The stated preference method values endpoints by using carefully structured surveys to ask a sample of people what amount of compensation is equivalent to an improvement in environmental quality. There is an extensive scientific literature and body of practice on both the theory and technique of stated preference-based valuation. Well-designed and well-executed stated preference studies are valid for estimating the benefits of air quality regulations.[G] Stated preference valuation studies form the complete or partial basis for valuing a number of health and welfare endpoints, including the value of mortality risk reductions, chronic bronchitis (CB) 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 VSL for use in estimating benefits from mortality risk reductions. No market exists 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

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[G] 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 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 understood and accepted by the respondent; 3) whether the 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.

infer information about the monetary values associated with changes in mortality risk (see Section 6.3.5).

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, although not all, 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 6.3.5). In general, avoided cost methods should be used only if there is no information available using other valuation methods (OMB Circular A-4 offers some additional caution on the use of avoided cost methods).

6.3.2 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[H] 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. Although many analyses assume that the income elasticity of WTP is unit elastic (i.e., a 10% higher real income level implies a 10% higher WTP to reduce risk changes), empirical evidence 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 benefits estimates in two different ways: through real income growth between the year a WTP study was conducted and the year for which benefits are estimated, and 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 Science Advisory Board (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" (U.S. EPA-SAB, 2000a). A recent advisory by another committee associated with the SAB, the Advisory Council on Clean Air Compliance Analysis, has provided conflicting advice. While agreeing with "the general principle that the willingness to pay to reduce mortality risks is likely to increase with growth in real income (U.S. EPA-SAB, 2004a, p. 52)" and that "The same increase should be assumed for the WTP for serious nonfatal health effects (U.S. EPA-SAB, 2004a, p. 52)," they note that "given the limitations and uncertainties in the available empirical evidence, the Council does not support the use of the proposed adjustments for aggregate income growth as part of the primary analysis (U.S. EPA-SAB, 2004a, p. 53)." Until these conflicting advisories have been

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[H] Income elasticity is a common economic measure equal to the percentage change in WTP for a 1% change in income.

reconciled, EPA will continue to adjust valuation estimates to reflect income growth using the methods described below, while providing sensitivity analyses for alternative income growth adjustment factors.

Based on a review of the available income elasticity literature, we adjusted 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 2020 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. Note that because of the variety of empirical sources used in deriving the income elasticities, there may appear to be inconsistencies in the magnitudes of the income elasticities relative to the severity of the effects (*a priori* one might expect that more severe outcomes would show less income elasticity of WTP). We have not imposed any additional restrictions on the empirical estimates of income elasticity. One explanation for the seeming inconsistency is the difference in timing of conditions. WTP for minor illnesses is often expressed as a short term payment to avoid a single epidsode. WTP for major illnesses and mortality risk reductions are based on longer term measures of payment (such as wages or annual income). Economic theory suggests that relationships become more elastic as the length of time grows, reflecting the ability to adjust spending over a longer time period. Based on this theory, it would be expected that WTP for reducing long term risks would be more elastic than WTP for reducing short term risks. We also expect that the WTP for improved visibility in Class I areas would increase with growth in real income. The relative magnitude of the income elasticity of WTP for visibility compared with those for health effects suggests that visibility is not as much of a necessity as health, thus, WTP is more elastic with respect to income. The elasticity values used to adjust estimates of benefits in 2020 and 2030 are presented in Table 6.3-1.

Table 6.3-1. 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	0.90

[a] Derivation of estimates can be found in Kleckner and Neumann (1999) and Chestnut (1997). COI estimates are assigned an adjustment factor of 1.0.

In addition to elasticity estimates, projections of real gross domestic product (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 used 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 (U.S. Bureau of Census, 2000). 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 used projections of real GDP provided in Kleckner and Neumann (1999) for the years 1990 to 2010.[I] We used projections of real GDP (in chained 1996 dollars) provided by Standard and Poor's (2000) for the years 2010 to 2024.[J] 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 calculated WTP adjustment factors for each of the elasticity estimates listed in Table 6.3-1. Benefits for each of the categories (minor health effects, severe and chronic health effects, premature mortality, and visibility) are adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor. Table 6.3-2 lists the estimated adjustment factors. Note that, for premature mortality, we applied the income adjustment factor to the present discounted value of the stream of avoided mortalities occurring over the lag period. Also note that because of a lack of data on the dependence of COI and income, and a lack of data on projected growth in average wages, no adjustments are made to benefits based on the COI approach or to work loss days and worker productivity. This assumption leads us to underpredict benefits in future years because it is likely that increases in real U.S. income would also result in increased COI (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).

Table 6.3-2. Adjustment Factors Used to Account for Projected Real Income Growth[a]

Benefit Category	2020	2030
Minor Health Effect	1.066	1.076
Severe and Chronic Health Effects	1.229	1.266
Premature Mortality	1.201	1.233
Visibility	1.517	1.613

[a] Based on elasticity values reported in Table 6.3-1, U.S. Census population projections, and projections of real GDP per capita.

6.3.3 Demographic Projections

Quantified and monetized human health impacts depend on the demographic characteristics of the population, including age, location, and income. We use 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 United States to take into account patterns of economic growth and migration. The sum of growth in

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[I] U.S. Bureau of Economic Analysis, Table 2A (1992$) (available 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.

[J] In previous analyses, we used the Standard and Poor's projections of GDP directly. This led to an apparent discontinuity in the adjustment factors between 2010 and 2011. We refined the method by applying the relative growth rates for GDP derived from the Standard and Poor's projections to the 2010 projected GDP based on the Bureau of Economic Analysis projections.

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, and populations 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-based 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 2030 based on historical rates of mortality, fertility, and migration.

The WP projections of county-level population are based on historical population data from 1969 through 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.

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 GDP and total U.S. populations. For consistency with the emissions and benefits modeling, we used national population estimates based on the U.S. Census Bureau projections.

6.3.4 Methods for Describing Uncertainty

The NRC (2002) highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates as well as the need for presenting these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In response to these comments, EPA has initiated the development of a comprehensive methodology for characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates

In the current analysis, consistent with the approach used in the RIA for the recent PM NAAQS, EPA continues to move forward on one of the key recommendations of the NRC – moving the assessment of uncertainties from its ancillary analyses into its main benefits presentation through the conduct of probabilistic analyses. In this proposed rule, EPA addressed key sources of uncertainty by Monte Carlo propagation of uncertainty in the concentration-response (C-R) functions and economic valuation functions through its base estimates as well as by continuing its practice of conducting a series of ancillary sensitivity analyses examining the impact of alternate assumptions on the benefits estimates. It should be noted that the Monte Carlo-generated distributions of benefits reflect only some of the uncertainties in the input parameters. Uncertainties associated with emissions, air quality modeling, populations, and baseline health effect incidence rates are not represented in the distributions of benefits of attaining alternative standards. Issues such as correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements will be addressed in future versions of the uncertainty framework.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85% to 95% of total benefits. Therefore, in characterizing the uncertainty related to the estimates of total benefits it is particularly important to attempt to characterize the uncertainties associated with this endpoint. As such the analysis for this rule incorporates the results of our recent expert elicitation to characterize uncertainty in the effect estimates used to estimate premature mortality resulting from exposures to PM into the main analysis. In collaboration with OMB, EPA completed a pilot expert elicitation in 2004, which was used to characterize uncertainty in the PM mortality C-R function in the Nonroad Diesel and CAIR RIAs. EPA has recently completed a full-scale expert elicitation that incorporated peer-review comments on the pilot application, and that provides a more robust characterization of the uncertainty in the premature mortality function. This expert elicitation was designed to evaluate uncertainty in the underlying causal relationship, the form of the mortality impact function (e.g., threshold versus linear models) and the fit of a specific model to the data (e.g., confidence bounds for specific percentiles of the mortality effect estimates). Additional issues, such as the ability of long-term cohort studies to capture premature mortality resulting from short-term peak PM exposures, were also addressed in the expert elicitation.

For this proposal, consistent with the approach used in the RIA for the recent PM NAAQS, EPA addressed key sources of uncertainty through Monte Carlo propagation of uncertainty in the C-R functions and economic valuation functions and through a series of sensitivity analyses examining the impact of alternate assumptions on the benefits estimates that are generated. It should be noted that the Monte Carlo-generated distributions of benefits reflect only some of the uncertainties in the input parameters. Uncertainties associated with emissions, air quality modeling, populations, and baseline health effect incidence rates are not represented in the distributions of benefits of attaining alternative standards.

Our distributions of total benefits do not completely represent full uncertainty because of the uncertainty in model elements discussed below (see Table 6.3-3). Uncertainty about specific aspects of the health and welfare estimation models is discussed in greater detail in the following sections. The estimated distributions of total benefits may not completely capture the shape and location of the actual distribution of total benefits.

6.3.4.1 Sources of Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty. This analysis is no exception. As outlined both in this and preceding chapters, many inputs were used to derive the final estimate of benefits, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI 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 its role 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 large impacts on total benefits.

Some key sources of uncertainty in each stage of the benefits analysis are the following:

- gaps in scientific data and inquiry;
- variability in estimated relationships, such as epidemiological effect estimates, introduced through differences in study design and statistical modeling;
- errors in measurement and projection for variables such as population growth rates;
- 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 6.3-3.

More specifically, there are key uncertainties in many aspects of the health impact functions used in our analyses. These are discussed in detail in the following section.

Table 6.3-3. Primary Sources of Uncertainty in the Benefits Analysis

1. Uncertainties Associated with Impact Functions ● The value of the PM effect estimate in each impact function. ● Application of a single impact function to pollutant changes and populations in all locations. ● Similarity of future-year impact functions to current impact functions. ● Correct functional form of each impact function. ● Extrapolation of effect estimates beyond the range of PM concentrations observed in the source epidemiological study. ● Application of some impact functions only to those subpopulations matching the original study population.
2. Uncertainties Associated with PM Concentrations ● Responsiveness of the models to changes in precursor emissions resulting from the control policy. ● Projections of future levels of precursor emissions, especially organic carbonaceous particle emissions. ● Model chemistry for the formation of ambient nitrate concentrations. ● Lack of speciation monitors in some areas requires extrapolation of observed speciation data. ● CMAQ model performance in the Western U.S., especially California indicates significant underprediction of $PM_{2.5}$.
3. Uncertainties Associated with PM Mortality Risk ● Differential toxicity of specific component species within the complex mixture of PM has not been determined. ● 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 that 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 therefore may not accurately represent the actual location-specific rates. ● Current baseline incidence rates may not approximate well baseline incidence rates in 2020 and 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 because of differences in income or other factors.
7. Uncertainties Associated with Aggregation of Monetized Benefits ● Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or unmonetized benefits are not included.

6.3.4.2 Uncertainties Associated with Health Impact Functions based on Reported Effect Estimates from the Epidemiological Literature

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. The 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 well designed and executed studies and may result in health effect estimates that vary considerably. Across-study variation can result from a variety of possible causes. Such differences might simply be associated with different measurement techniques. Sources of variation can be introduced by the air quality monitoring technique, measurement averaging times, health endpoint data sources (differences in the way medical records are kept at different institutions or questionnaire wording). One possibility is that estimates of the single true relationship between a given pollutant and a health effect differ across studies because of 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 differences in the relative sensitivity of these two populations to PM pollution and differences in the composition of PM in these two locations, as well as other factors. 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. Regardless of the use of impact functions based on effect estimates from a single epidemiological study or multiple studies, each impact function was applied uniformly throughout the United States to generate health benefit estimates. However, to the extent that pollutant/health effect relationships are region specific, applying a location-specific impact function at all locations in the United States 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 applying a single impact function to the entire United States. 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 for most health outcomes.[K]

Extrapolation of Impact Functions Across Populations. Epidemiological studies often focus on specific age ranges, either due to data availability limitations (e.g., most hospital admission data come from Medicare records, which are limited to populations 65 and older), or to simplify

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[K] Although we are not able to use region-specific effect estimates, 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.

data collection (e.g., 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 most impact functions should be applied only to those populations with ages that strictly match the populations in the underlying epidemiological studies. However, 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. In response to recommendations from the SAB-HES, where there appears to be a reasonable physiological basis for expanding the age group associated with a specific effect estimate beyond the study population to cover the full age group (e.g., expanding from a study population of 7 to 11 year olds to the full 6- to 18-year child age group), we have done so and used those expanded incidence estimates in the primary analysis.

Uncertainties in Concentration-Response Functions. The following uncertainties exist in almost all concentration-response functions for PM-related health effects. For expository purposes, and because of the importance of mortality, we focus the discussion on how these uncertainties affect the PM mortality concentration-response functions.

Causality: Epidemiological studies are not designed to definitively prove causation. For the analysis of the proposed standards, 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 (CASAC, 2005). As with all health effects included in our analysis, a weight of evidence process is used to evaluate endpoints before including them in the analysis.

Other Pollutants: PM concentrations are correlated with the concentrations of other criteria pollutants, such as ozone and CO. To the extent that there is correlation, this analysis may be assigning mortality effects to PM exposure that are actually the result of exposure to other pollutants. Recent studies suggest that ozone may have mortality effects independent of PM.

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 has a non-threshold log-linear form 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 misestimated.

In addition, there is ongoing debate as to whether there exists a threshold below which there would be no benefit to further reductions in $PM_{2.5}$. Some researchers have hypothesized the presence of a threshold relationship. The nature of the hypothesized relationship is the possibility that there exists a PM concentration level below which further reductions no longer yield premature mortality reduction benefits. EPA's most recent $PM_{2.5}$ Criteria Document concludes that "the available evidence does not either support or refute the existence of thresholds for the effects of PM on mortality across the range of concentrations in the studies" (U.S. EPA, 2004b, p. 9-44). EPA's Science Advisory Board (SAB) that provides advice on benefits analysis methods[L] has recommended modeling 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.

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 misestimation of effects in these regions.

Relative Toxicity of PM Component Species: In this analysis, all fine particles, regardless of their chemical composition, are assumed to be equally potent in causing premature mortality. This is an important assumption, because there may be significant differences between PM produced via transported precursors, direct PM released from automotive engines, and direct PM from other industrial sources. The analysis also assumes that all components of fine particles have equal toxicity (because the available epidemiological effect estimates are based on total $PM_{2.5}$ mass rather than the mass of individual component species). While it is reasonable to expect that the potency of components may vary across the numerous effect categories associated with particulate matter, EPA's interpretation of scientific information considered to date is that such information does not yet provide a basis for quantification beyond using fine particle mass. However, to provide information that may be useful as additional studies become available, we are providing estimates of the proportions of benefits that are attributable to specific components of $PM_{2.5}$, e.g., ammonium sulfate, ammonium nitrate, elemental carbon, organic carbon, and crustal material (which includes metals). This apportionment does not make any assumptions about the relative toxicity of the different species; rather, it divides total benefits based on the contribution of reductions in individual component species to the overall reduction in $PM_{2.5}$ mass.

Lag Time Between Change in Exposure and Health Impact: There is a time lag between changes in PM exposures and the total realization of changes in health effects. Within the context of benefits analyses, this term is often referred to as "cessation lag." For the chronic PM/mortality relationship, the length of the cessation lag is unknown. 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 health effects cessation lag for reductions in exposures to fine PM.

[L] The advice from the 2004 SAB-HES (U.S. EPA-SAB, 2004b) is characterized by the following: "For the studies of long-term exposure, the HES notes that Krewski et al. (2000) have conducted the most careful work on this issue. They report that the associations between $PM_{2.5}$ and both all-cause and cardiopulmonary mortality were near linear within the relevant ranges, with no apparent threshold. Graphical analyses of these studies (Dockery et al., 1993, Figure 3, and Krewski et al., 2000, page 162) also suggest a continuum of effects down to lower levels. Therefore, it is reasonable for EPA to assume a no threshold model down to, at least, the low end of the concentrations reported in the studies."

Information about latency (the amount of time between exposure and onset of a health effect) may inform our understanding of cessation lags.

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 suggests 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, although it is worth noting here that in the case of ambient air pollution we are predicting the effects of reduced exposure rather than complete cessation. The SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate. Diseases with longer progressions should be characterized by long-term lag structures, while impacts occurring in populations with existing disease may be characterized by short-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the cohort studies used. While we may be more certain about the appropriate length of cessation lag for lung cancer deaths, it is not clear what the appropriate lag structure should be for different types of cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags.

The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including the use of disease-specific lag models, and the construction of a segmented lag distribution to combine differential lags across causes of death. The SAB-HES recommended that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30% of mortality reductions occurring in the first year, 50% occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20% occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004). The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. For future analyses, the specific distribution of deaths over time will need to be determined through research on causes of death and progression of diseases associated with air pollution. 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.

Cumulative Effects: 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 are still uncertain at this time.

6.3.5 Health Benefits Assessment Methods

The largest 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 (EPA, 2006; 2006). As discussed above, quantification of health impacts requires several inputs, including epidemiological effect estimates (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 effect estimates 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. These include premature mortality, nonfatal heart attacks, chronic bronchitis, acute bronchitis, hospital admissions, emergency room visits for asthma, upper and lower respiratory symptoms, asthma exacerbations, minor restricted activity days and days of work lost.

As discussed above, we have chosen to not include estimates of ozone-related health effects in this analysis, though the proposed standards are expected to reduce ambient levels of ozone. Some health effects are excluded from this analysis for three reasons: the possibility of double-counting, uncertainties in applying effect relationships based on clinical studies to the affected population, or a lack of an established relationship between the health effect and pollutant in the published epidemiological literature. Unquantifed effects are listed in Table 6.1-2. An improvement in ambient $PM_{2.5}$ and ozone air quality may reduce the number of incidences within each unquantified effect category that the U.S. population would experience. Although these health effects are believed to be PM and ozone induced, effect estimates 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.

6.3.5.1 Selection of Health Endpoints

We base our selection of health endpoints on consistency with EPA Criteria Documents and Staff Papers, with input and advice from the EPA Science Advisory Board Health Effects Subcommittee, a scientific review panel specifically established to provide advice on the use of the scientific literature in developing benefits analyses for air pollution regulations (http://www.epa.gov/sab/). In general, we follow a weight of evidence approach, based on the biological plausibility of effects, availability of concentration-response functions from well-conducted peer-reviewed epidemiological studies, cohesiveness of results across studies, and a focus on endpoints reflecting public health impacts (like hospital admissions) rather than physiological responses (such as changes in clinical measures like Forced Expiratory Volume (FEV1)).

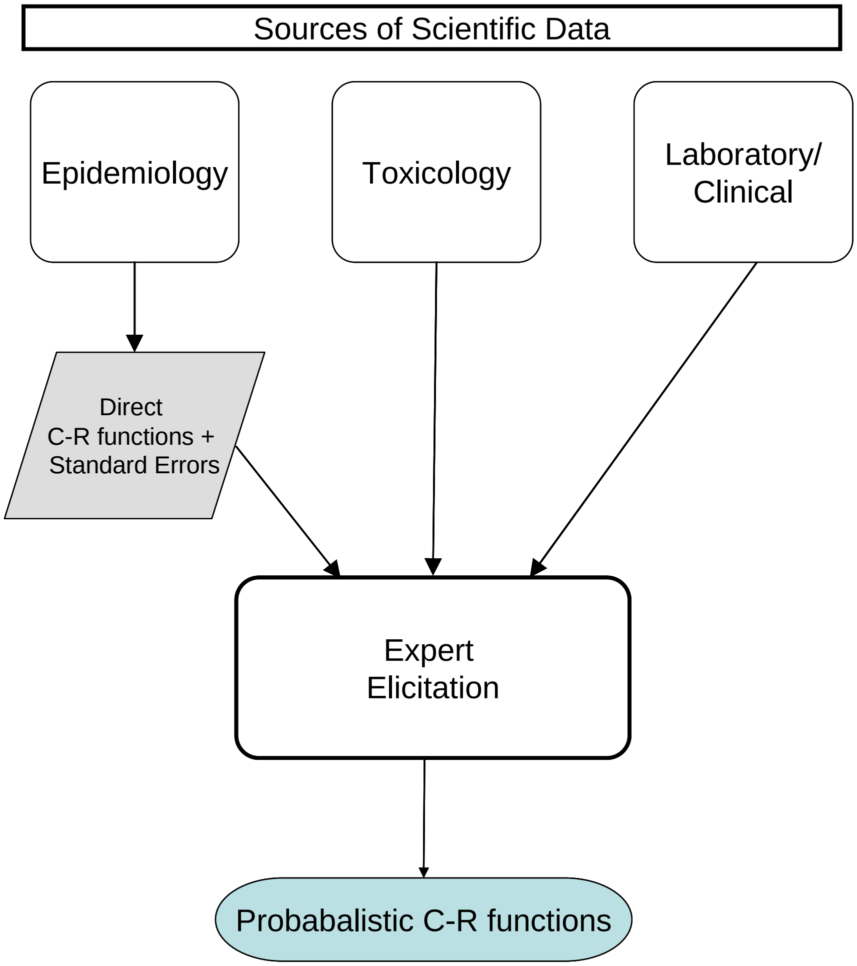
6.3.5.2 Sources of Information for Effect Estimates

There are several types of data that can support the determination of types and magnitude of health effects associated with air pollution exposures. These sources of data include toxicological studies (including animal and cellular studies), human clinical trials, and observational epidemiology studies. All of these data sources provide important contributions to the weight of evidence surrounding a particular health impact, however, only epidemiology studies provide direct concentration-response relationships which can be used to evaluate population-level impacts of reductions in ambient pollution levels.

However, standard environmental epidemiology studies provide only a limited representation of the uncertainty associated with a specific C-R function, measuring only the statistical error in the estimates, and usually relating more to the power of the underlying study (driven largely by population size and the frequency of the outcome measure). There are many other sources of uncertainty in the relationships between ambient pollution and population level health outcomes, including many sources of model uncertainty, such as model specification, potential confounding between factors that are both correlated with the health outcome and each other, and many other factors. As such, in recent years, EPA has begun investigating how expert elicitation methods can be used to integrate across various sources of data in developing C-R functions for regulatory benefits analyses.

Expert elicitation is useful in integrating the many sources of information about uncertainty in the C-R function, because it allows experts to synthesize these data sources using their own mental models, and provide a probabilistic representation of their synthesis of the data in the form of a probability distribution of the C-R function. Figure 6.3-1 shows how expert elicitation builds on both the direct empirical data on C-R relationships and other less direct evidence to develop probabilistic distributions of C-R functions. EPA has used expert elicitation to inform the regulatory process in the past (see for example the previous staff paper for the lead NAAQS, U.S. EPA, 1990). In the current analysis, we have only used expert elicitation to characterize the C-R function for the relationship between fine PM and premature mortality. However, similar methods could be used to characterize C-R functions for other health outcomes.

Figure 6.3-1. Sources and Integration of Scientific Data in Informing Development of Health Impact Functions



6.3.5.3 Information Used in Quantifying C-R Functions

For the data-derived estimates, we relied on the published scientific literature to ascertain the relationship between PM and adverse human health effects. We evaluated epidemiological studies using the selection criteria summarized in Table 6.3-4. 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.

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, making 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 because of 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 effect estimate.

When several effect estimates for 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 BenMAP Technical Appendices provides details of the procedures used to combine multiple impact functions (Abt Associates, 2005). In general, we used fixed or random effects models to pool estimates from different studies of the same endpoint. Fixed effects pooling simply weights each study's 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 used the fixed effects model as our null hypothesis and then determined whether the data suggest that we should reject this null hypothesis, in which case we would use the random effects model.[M] Pooled impact functions are used to estimate hospital admissions and asthma exacerbations. For more details on methods used to pool incidence estimates, see the BenMAP Technical Appendices (Abt Associates, 2005), which are available with the BenMAP software at http://www.epa.gov/ttn/ecas/benmodels.html.

Effect estimates selected for a given health endpoint were applied consistently across all locations nationwide. This applies to both impact functions defined by a single effect estimate and those defined by a pooling of multiple effect estimates. Although the effect estimate may, in fact, vary from one location to another (e.g., because of differences in population susceptibilities or differences in the composition of PM), location-specific effect estimates are generally not available.

The specific studies from which effect estimates for the primary analysis are drawn are included in Table 6.3-5. In all cases where effect estimates are drawn directly from epidemiological studies, standard errors are used as a partial representation of the uncertainty in the size of the effect estimate. Detailed information about the form and parameters of each impact function used in this analysis can be found in the BenMAP users manual.[N] For those functions not included in the BenMAP users manual, we include a technical memo to the docket for this rule. Below we provide the basis for selecting these studies.

[M] In this analysis, the fixed effects model assumes that there is only one pollutant coefficient for the entire modeled area. The random effects model assumes that studies conducted in different locations are estimating different parameters; therefore, there may be a number of different underlying pollutant coefficients.

[N] Interested parties may wish to consult the webpage http://www.epa.gov/ttn/ecas/benmodels.html to download the BenMAP users manual. The users manual is also included in the docket for this rule.

Table 6.3-4 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 ecological studies because they control for important individual-level confounding variables that cannot be controlled for in ecological 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 lifestyle over time. However, when there are only a few studies available, studies from all years will be included.
Population Attributes	The most technically appropriate measures of benefits would be based on impact functions that cover the entire sensitive population but allow for heterogeneity across age or other relevant demographic factors. In the absence of effect estimates specific to age, sex, preexisting condition status, or other relevant factors, it may be appropriate to select effect estimates that cover the broadest population to match with the desired outcome of the analysis, which is total national-level health impacts. When available, multi-city studies are preferred to single city studies because they provide a more generalizable representation of the C-R function.
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 (e.g., 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 lifestyle.
Pollutants Included in Model	When modeling the effects of ozone and PM (or other pollutant combinations) jointly, it is important to use properly specified impact functions that include both pollutants. Using 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, impact functions based on $PM_{2.5}$ are preferred to PM_{10} because of the focus on reducing emissions of $PM_{2.5}$ precursors, and because air quality modeling was conducted for this size fraction of PM. 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.
Nonoverlapping 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.

Table 6.3-5. Endpoints and Studies Used to Calculate Total Monetized Health Benefits

Endpoint	Pollutant	Study	Study Population
Premature Mortality			
Premature mortality — cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[9] Laden et al. (2006)[10]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[11]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[12]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[13]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[14]	Adults
Hospital Admissions			
Respiratory	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[15] Ito (2003)—ICD 490-496 (COPD)[16]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[17]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[18]	<65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—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	$PM_{2.5}$	Norris et al. (1999)[19]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[20]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[21]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[22]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[23] (cough, wheeze and shortness of breath) Vedal et al. (1998)[24] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[25]	18–65 years
MRADs	$PM_{2.5}$	Ostro and Rothschild (1989)[26]	18–65 years

[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the SAB-HES, we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group.

$PM_{2.5}$-Related Adult Premature Mortality – Epidemiological Basis.

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 epidemiological studies, the serious nature of the effect itself, and the high monetary value ascribed to prolonging life make mortality risk reduction the most significant health endpoint quantified in this analysis.

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 (US EPA, 2004). Time-series methods have been used 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. Cohort methods have been used to examine the potential relationship between community-level PM exposures over multiple years (i.e., long-term exposures) 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 cohort studies are larger than those derived from time-series studies. Cohort analyses are thought to better capture the full public health impact of exposure to air pollution over time, because they capture the effects of long-term exposures and possibly some component of short-term exposures (Kunzli et al., 2001; NRC, 2002). This section discusses some of the issues surrounding the estimation of premature mortality. To demonstrate the sensitivity of the benefits estimates to the specific sources of information regarding the impact of PM2.5 exposures on the risk of premature death, we are providing estimates in our results tables based on studies derived from the epidemiological literature and from the recent EPA sponsored expert elicitation. The epidemiological studies from which these estimates are drawn are described below. The expert elicitation project and the derivation of effect estimates from the expert elicitation results are described in the next section.

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). However, exploration of alternative model specifications sometimes raised questions about causal relationships (e.g., Lipfert, Morris, and Wyzga [1989]). These early “ecological 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. Over the last 10 years, several studies using “prospective cohort” designs have been published that 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 analyses have been based on data from two prospective cohort groups, often referred to as the Harvard “Six-Cities Study” (Dockery et al., 1993; Laden et al, 2006) and the “American Cancer Society or ACS study” (Pope et al., 1995; Pope et al, 2002; Pope et al, 2004); these studies have found consistent relationships between fine particle indicators and premature mortality across multiple locations in the United States. 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 United States, and the lifestyle of the population is not reflective of much of the U.S. population.

Analysis is also available for a cohort of adult male veterans diagnosed with hypertension has been examined (Lipfert et al., 2000; Lipfert et al, 2003, 2006). The characteristics of this group differ from the cohorts in the Six-Cities, ACS, and 7th Day Adventist studies with respect to income, race, health status, and smoking status. Unlike previous long-term analyses, this study found some associations between mortality and ozone but found inconsistent results for PM indicators. Because of the selective nature of the population in the veteran's cohort, we have chosen not to include any effect estimates from the Lipfert et al. (2000) study in our benefits assessment.[O]

Given their consistent results and broad geographic coverage, and importance in informing the NAAQS development process, the Six-Cities and ACS data have been particularly important in benefits analyses. The credibility of these two studies is further enhanced by the fact that the initial published studies (Pope et al, 1995 and Dockery et al 1993) were subject to extensive reexamination and reanalysis by an independent team of scientific experts commissioned by HEI (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. While the HEI reexamination lends credibility to the original studies, it also highlights sensitivities concerning the relative impact of various pollutants, such as SO2, the potential role of education in mediating the association between pollution and mortality, and the influence of spatial correlation modeling.

Further confirmation and extension of the findings of the 1993 Six City Study and the 1995 ACS study were recently completed using more recent air quality and a longer follow-up period for the ACS cohort was recently published (Pope et al, 2002, 2004; Laden et al, 2006). The follow up to the Harvard Six City Study both confirmed the effect size from the first analysis and provided additional confirmation that reductions in $PM_{2.5}$ are likely to result in reductions in the risk of premature death. This additional evidence stems from the observed reductions in $PM_{2.5}$ in each city during the extended follow-up period. Laden et al. (2006) found that mortality rates consistently went down at a rate proportionate to the observed reductions in $PM_{2.5}$.

The extended analyses of the ACS cohort data (Pope et al., 2002, 2004) provides additional refinements to the analysis of PM-related mortality by a) extending the follow-up period for the ACS study subjects to 16 years, which triples the size of the mortality data set; b)

[O] EPA recognizes that the ACS cohort also is not representative of the demographic mix in the general population. The ACS cohort is almost entirely white and has higher income and education levels relative to the general population. EPA's approach to this problem is to match populations based on the potential for demographic characteristics to modify the effect of air pollution on mortality risk. Thus, for the various ACS-based models, we are careful to apply the effect estimate only to ages matching those in the original studies, because age has a potentially large modifying impact on the effect estimate, especially when younger individuals are excluded from the study population. For the Lipfert analysis, the applied population should be limited to that matching the sample used in the analysis. This sample was all male, veterans, and diagnosed hypertensive. There are also a number of differences between the composition of the sample and the general population, including a higher percentage of African Americans (35%) and a much higher percentage of smokers (81% former smokers, 57% current smokers) than the general population (12% African American, 24% current smokers).

substantially increasing exposure data, including additional measurement of cohort exposure to $PM_{2.5}$ following implementation of the $PM_{2.5}$ standard in 1999; c) controlling for a variety of personal risk factors including occupational exposure and diet; and d) using advanced statistical methods to evaluate specific issues that can adversely affect risk estimates including the possibility of spatial autocorrelation of survival times in communities located near each other.

The NRC (2002) also recommended that EPA review the database of cohort studies and consider developing a weighted mean estimate based on selected studies. Because of the differences in the study designs and populations considered in the ACS and Harvard Six-cities studies, we have elected to not pool the results of the studies, instead presenting a range of estimates reflecting the different sources of impact estimates.

In developing and improving the methods for estimating and valuing the potential reductions in mortality risk over the years, EPA consulted with the SAB-HES. That panel recommended using long-term prospective cohort studies in estimating mortality risk reduction (U.S. EPA,1999b). 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" (NRC, 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. Because of the refinements in the extended follow-up analysis, the SAB-HES recommends using the Pope et al. (2002) study as the basis for the primary mortality estimate for adults and suggests that alternate estimates of mortality generated using other cohort and time-series studies could be included as part of the sensitivity analysis (U.S. EPA-SAB, 2004b).

The SAB-HES also recommended using the specific estimated relative risks from the Pope et al. (2002) study based on the average exposure to $PM_{2.5}$, measured by the average of two $PM_{2.5}$ measurements, over the periods 1979–1983 and 1999–2000. In addition to relative risks for all-cause mortality, the Pope et al. (2002) study provides relative risks for cardiopulmonary, lung cancer, and all-other cause mortality. Because of concerns regarding the statistical reliability of the all-other cause mortality relative risk estimates, we calculated mortality impacts for the primary analysis based on the all-cause relative risk. Based on our most recently available SAB guidance, we provide mortality impacts based on the ACS study as the best estimate for comparing across the current and previous RIAs. This provides historical continuity with past analyses and serves as one point of reference in interpreting the results of the expert elicitation (see discussion below).

The RIAs for the CAIR and Clean Air Nonroad Diesel rules included an estimate of mortality impacts based on application of the C-R function derived from the Harvard Six-cities study. In those analyses, the Six-cities estimate was included as a sensitivity analysis in an appendix to the RIA. Following the NAS advice to begin moving sensitivity and uncertainty analyses into the main body of the RIA, we are including a separate estimate based on the Six-cities study to complement the estimate based on the ACS study. This also reflects the weight that was placed on both the ACS and Harvard Six-city studies by experts participating in the $PM_{2.5}$ mortality expert elicitation.

As noted above, since the most recent SAB review, an extended follow-up of the Harvard Six-cities study has been published (Laden et al., 2006). We use this specific estimate to represent the Six-cities study because it reflects the most up-to-date science and because it was cited by many of the experts in their elicitation responses. We note that because of the recent publication date of the Laden et al (2006) study, it has not undergone the CASAC and SAB-HES review received by the Pope et al (2002) and earlier Six-cities publications (see Dockery et al, 1993). However, it is clear from the expert elicitation that the results published in Laden et al (2006) are potentially influential, and in fact, the expert elicitation results encompass within their range the estimates from both the Pope et al (2002) and Laden et al (2006) studies. As part of the NAAQS review process, EPA conducted a provisional assessment of “new” science published since the closing date for the PM Criteria Document. The provisional assessment found that “new” studies generally strengthen the evidence that acute and chronic exposures to fine particles are associated with health effects. The provisional assessment found that the results reported in the studies do not dramatically diverge from previous findings, and, taken in context with the findings of the Criteria Document, the new information and findings do not materially change any of the broad scientific conclusions regarding the health effects of PM exposure made in the Criteria Document. The Laden et al (2006) study was included in this provisional assessment and therefore can be considered to be covered under the broad findings of the provisional assessment.

A number of additional analyses have been conducted on the ACS cohort data (Jarrett et al., 2005; Krewski et al., 2005; Pope et al., 2004). These studies have continued to find a strong significant relationship between $PM_{2.5}$ and mortality outcomes. Specifically, much of the recent research has suggested a stronger relationship between cardiovascular mortality and lung cancer mortality with $PM_{2.5}$, and a less significant relationship between respiratory-related mortality and $PM_{2.5}$.

EPA’s is committed to seeking the advice of its Science Advisory Board to review how EPA has incorporated expert elicitation results into the benefits analysis, and the extent to which they find the presentation in this RIA responsive to the NRC (2002) guidance to incorporate uncertainty into the main analysis and further, whether the agency should move toward presenting a central estimate with uncertainty bounds or continue to provide separate estimates for each of the 12 experts as well as from the ACS and Six Cities studies, and if so, the appropriateness of using Laden et al 2006, the most recently published update, as the estimate for the Six Cities based model.

$PM_{2.5}$-Related Adult Premature Mortality – Expert Elicitation Study

Among the recommendations made by the National Research Council (NRC) in its 2002 review of EPA's method for assessing health benefits of air pollution regulations was a recommendation for EPA to consider the use of formally elicited expert judgments as a means of characterizing uncertainty in inputs to health benefits analyses. As part of its efforts to improve the characterization of uncertainties in its benefits estimates, EPA has conducted a study of the concentration-response (C-R) relationship between changes in $PM_{2.5}$ exposures and mortality using formally elicited expert judgments. The goal of the study was to elicit from a sample of health experts probabilistic distributions describing uncertainty in estimates of the reduction in mortality among the adult U.S. population resulting from reductions in ambient annual average

$PM_{2.5}$ levels. These distributions were obtained through a formal interview protocol using methods designed to elicit subjective expert judgments.

In 2003 and 2004, EPA conducted a pilot-scale elicitation study with five experts to explore the effectiveness of expert judgment techniques for characterizing uncertainty and to explore the use of the expert judgment results in the context of economic benefits analysis (Industrial Economics, 2004). EPA previously applied the results of the pilot-scale study as part of its uncertainty analysis in the regulatory analysis accompanying the Clean Air Interstate Rule (CAIR) (U.S. EPA, 2005). EPA has recently completed a full-scale expert elicitation analysis of the PM2.5-mortality relationship that included numerous refinements based on insights from conducting the pilot study and on comments from peer reviewers of the pilot (Industrial Economics, 2006). This analysis applies the results of the full-scale study.

The full-scale study involved personal interviews with twelve health experts who have conducted research on the relationship between $PM_{2.5}$ exposures and mortality. These experts were selected through a peer-nomination process and included experts in epidemiology, toxicology, and medicine. The elicitation interview consisted of a protocol of carefully structured questions, both qualitative and quantitative, about the nature of the $PM_{2.5}$-mortality relationship.[P] The questions requiring qualitative responses probed experts' beliefs concerning key evidence and critical sources of uncertainty and enabled them to establish a conceptual basis supporting their quantitative judgments. Questions covered topics such as potential biological mechanisms linking $PM_{2.5}$ exposures with mortality; the role of study design in capturing PM/mortality effects; key scientific evidence on the magnitude of the PM/mortality relationship; sources of potential error or bias in epidemiological results; the likelihood of a causal relationship between $PM_{2.5}$ and mortality, and the shape of the C-R function. The main quantitative question in the protocol asked experts to provide the 5th, 25th, 50th, 75th, and 95th percentiles of a probabilistic distribution for the percent change in U.S. annual, adult all-cause mortality resulting from a 1 $\mu g/m^3$ change in annual average $PM_{2.5}$ exposure, assuming a range of baseline PM2.5 levels between 4 and 30 $\mu g/m^3$. This quantitative question was designed to yield results appropriate for application in EPA's quantitative health benefit analyses.

[P] In addition to the elicitation interviews, the twelve experts participated in pre- and post-elicitation workshops. The pre-elicitation workshop was designed to prepare the experts by familiarizing them with the protocol, providing them information about probabilistic judgments, and allowing them to discuss key issues and relevant evidence. At this workshop, the experts were also provided with “briefing book” materials, including a CD containing relevant studies and background information pages with data on air quality in the US, population demographics, health status, summaries of published effect estimates, and data on other factors potentially useful to experts in developing their judgments (air conditioning use, housing stock, PM composition, educational attainment). The post-elicitation workshop was designed to anonymously share and discuss results of the expert interviews; discuss key areas where expert opinion varied; and clarify any questions that may have arisen during the interviews. Experts were given the opportunity to revise their judgments in response to discussions at this workshop; however, experts were not encouraged to reach a consensus opinion.

The results of the full-scale study consist of twelve individual distributions for the coefficient or slope of the C-R function relating changes in annual average $PM_{2.5}$ exposures to annual, adult all-cause mortality. The results have not been combined in order to preserve the breadth and diversity of opinion on the expert panel. In applying these results in a benefits analysis context, EPA incorporates information about each expert's judgments concerning the shape of the C-R function (including the potential for a population threshold $PM_{2.5}$ concentration below which there is no effect on mortality), the distribution of the slope of the C-R function, and the likelihood that the $PM_{2.5}$-mortality relationship is or is not causal (unless the expert incorporated this last element directly in his slope distribution - see Industrial Economics, 2006).

Consistent with the approach used in the RIA for the recent PM NAAQS, we constructed a corresponding set of 12 health impact functions for premature mortality based on the responses of the 12 experts (designated A through L). For those experts providing log-linear non-threshold functions, construction of a health impact function was straightforward, and directly matched the construction of health impact functions based on the epidemiology literature.[Q] In these cases, the expert's function can be translated into a health impact function of the form:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta PM} - 1\right),$$

Where y_0 is the baseline incidence, equal to the baseline incidence rate time the potentially affected population, β is the effect estimate provided by the expert, and ΔPM is the change in $PM_{2.5}$.

Some experts specified a piecewise log-linear function, in which case we developed health impact functions that incorporate ambient concentration levels. For example, Expert B specified a piecewise function with two segments, representing the concentration-response function for ambient concentrations between 4 and 10 µg/m^3 and between 10 and 30 µg/m^3. In this case, the expert's function can be translated into a health impact function of the form:

$$\Delta y = \begin{cases} y_{01} \cdot \left(e^{\beta_1 \cdot \Delta PM} - 1\right) if\ Q_0 < 10 \\ y_{02} \cdot \left(e^{\beta_2 \cdot \Delta PM} - 1\right) if\ Q_0 \geq 10 \end{cases},$$

Where Q_0 is the baseline concentration of $PM_{2.5}$, y_{01} is the baseline incidence for populations living in areas with baseline concentrations of $PM_{2.5}$ less than 10 µg/m^3, y_{02} is the baseline incidence for populations living in areas with baseline concentrations of $PM_{2.5}$ greater than or equal to10 µg/m^3, and β_1 and β_2 are the effect estimates corresponding to the segments of the C-R function relating to ambient concentrations between 4 and 10 µg/m^3 and 10 and 30 µg/m^3, respectively.

[Q] Note that in the expert elicitation protocol, we specified the relevant range of exposure as between 4 and 30 µg/m^3. As such, when applying the expert elicitation based functions, benefits are only estimated for starting concentrations greater than 4 µg/m^3.

A third form specified by one expert (Expert K) included both a piecewise log-linear function and a probabilistic threshold. Expert K did not provide a full set of information about the shape of the distribution of the threshold, providing only the probability that a threshold existed between 0 and 5 µg/m^3 (equal to 0.4) and the probability that a threshold existed between 5 and 10 µg/m^3 (equal to 0.1). The probability that a threshold above 10 existed was set to zero, and the probability that there was no threshold was specified as 0.50. We assumed that the probability distribution across the range 0 to 5 was uniform, such that the probability of a threshold between 0 and 1, 1 and 2, etc. was equal. Likewise, we assumed that the probability distribution across the range 5 to 10 was uniform. Expert K also provided a two segment piecewise log-linear function, with the segments defined over the ranges 4 to 16 µg/m^3, and 16 to 30 µg/m^3. Using this information, we translated Expert K's responses into the following three conditional health impact functions:

$$\text{(K1)}\qquad \Delta y = \begin{cases} y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right) if\ Q_0 < 16 \\ y_{02}\cdot\left(e^{\beta_2\cdot\Delta PM}-1\right) if\ Q_0 \geq 16 \end{cases}$$

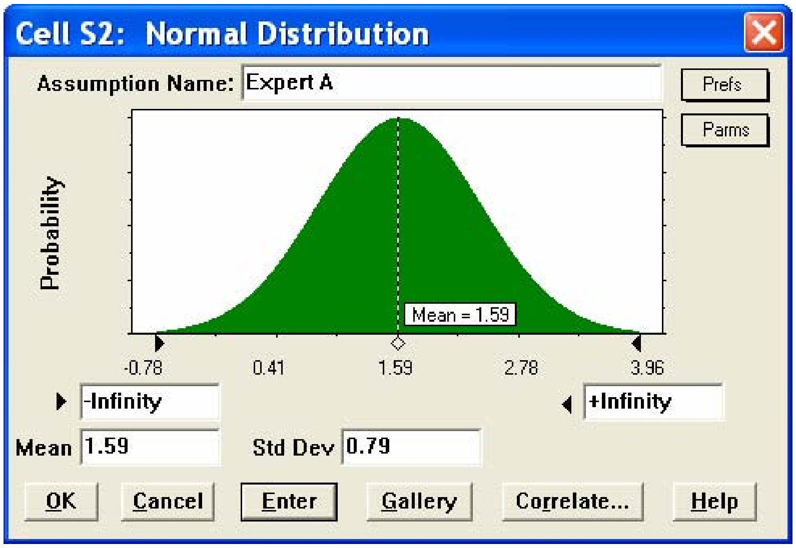
$$\text{(K2)}\qquad \Delta y = \begin{cases} y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.0 if\ 0 \leq Q_0 < 1 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.2\ if\ 1 \leq Q_0 < 2 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.4\ if\ 2 \leq Q_0 < 3 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.6\ if\ 3 \leq Q_0 < 4 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.8 if\ 4 \leq Q_0 < 5 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right) if\ 5 \leq Q_0 < 16 \\ y_{02}\cdot\left(e^{\beta_2\cdot\Delta PM}-1\right) if\ Q_0 \geq 16 \end{cases}$$

$$\text{(K3)}\qquad \Delta y = \begin{cases} y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.0 if\ 0 \leq Q_0 < 6 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.2\ if\ 6 \leq Q_0 < 7 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.4\ if\ 7 \leq Q_0 < 8 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.6\ if\ 8 \leq Q_0 < 9 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 0.8 if\ 9 \leq Q_0 < 10 \\ y_{01}\cdot\left(e^{\beta_1\cdot\Delta PM}-1\right)\times 1.0 if\ 10 \leq Q_0 < 16 \\ y_{02}\cdot\left(e^{\beta_2\cdot\Delta PM}-1\right) if\ Q_0 \geq 16 \end{cases}$$

Function K1 is associated with a no threshold segmented log-linear specification with a knot at 16 µg/m^3. Function K2 represents the segmented log-linear function with a threshold between 0 and 5 µg/m^3, with the cumulative probability of a threshold at or below the initial concentration Q_0 increasing as Q_0 decreases (this will result in a declining expected value of the impact at lower initial concentrations). Likewise, function K3 represented the segmented log-linear function with a threshold between 5 and 10 µg/m^3. The results of applying the three conditional functions are then combined using Monte Carlo analysis with weights of 0.5, 0.4, and 0.1 assigned to conditional functions K1, K2, and K3, respectively.

In addition to specifying a function form, each expert provided a representation of the distribution (or distributions for those who specified piecewise functions) of the effect size (in terms of the percent change in premature mortality associated with a one microgram change in annual mean $PM_{2.5}$). Six of the experts simply chose a normal distribution, which is completely specified with two parameters, the mean and standard deviation (see Figure 6.3-2 for example). In one case, the expert specified a triangular distribution, which is represented by a minimum, maximum, and most likely value (see Figure 6.3-3). In another case, the expert specified a Weibull distribution, which has three parameters representing scale, location, and shape (see Figure 6.3-4). Four of the experts did not choose a parametric distribution, preferring instead to provide only effect estimates at particular percentiles of their distributions. In these cases, we constructed custom distributions to represent their percentiles. For these custom distributions, we assume a continuous and smooth transition of the distribution between the reported percentiles (see Figure 6.3-5 for example).

Figure 6.3-2. Example Normal Distribution for Expert A



Cell S2: Normal Distribution

Assumption Name: Expert A

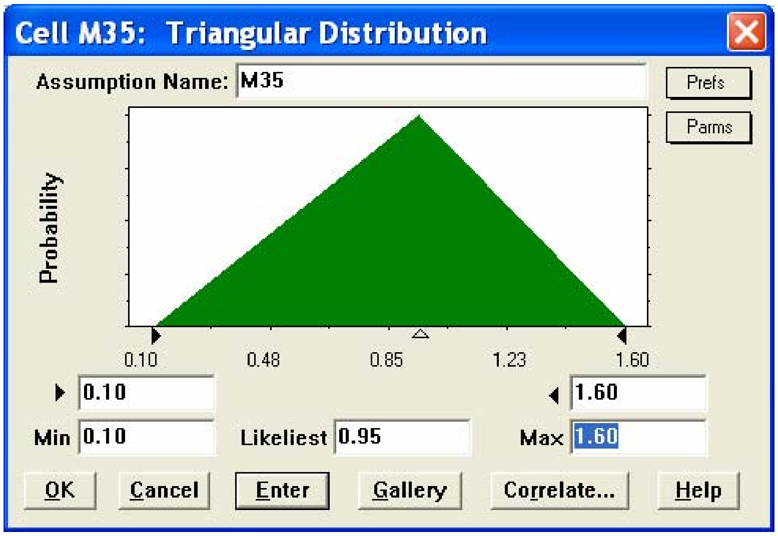
-Infinity

+Infinity

Mean 1.59

Std Dev 0.79

Figure 6.3-3. Example Triangular Distribution for Expert D



Cell M35: Triangular Distribution

Assumption Name: M35

0.10

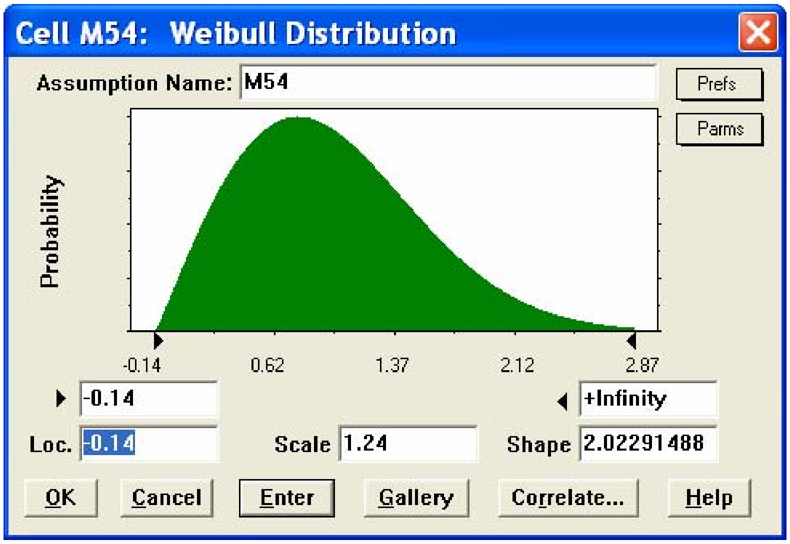
1.60

Min 0.10

Likeliest 0.95

Max 1.60

Figure 6.3-4. Example Weibull Distribution for Expert J



Cell M54: Weibull Distribution

Assumption Name: M54

-0.14

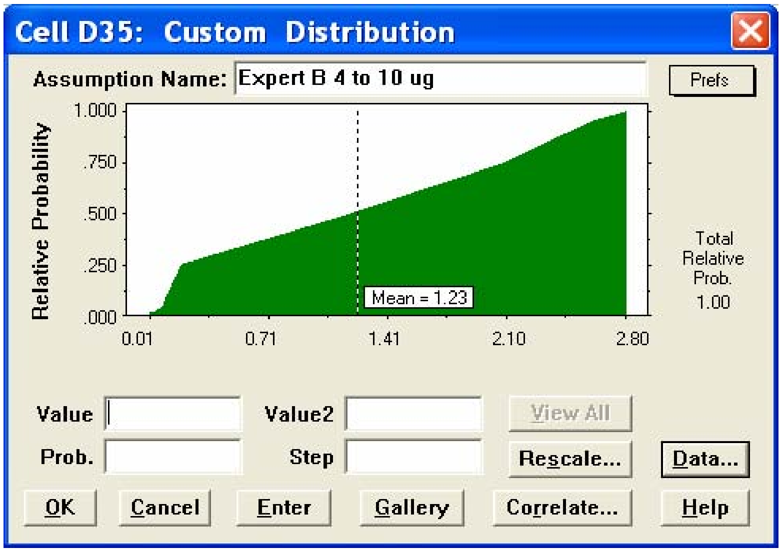
+Infinity

Loc. -0.14

Scale 1.24

Shape 2.02291488

Figure 6.3-5. Example Custom Distribution for Expert B



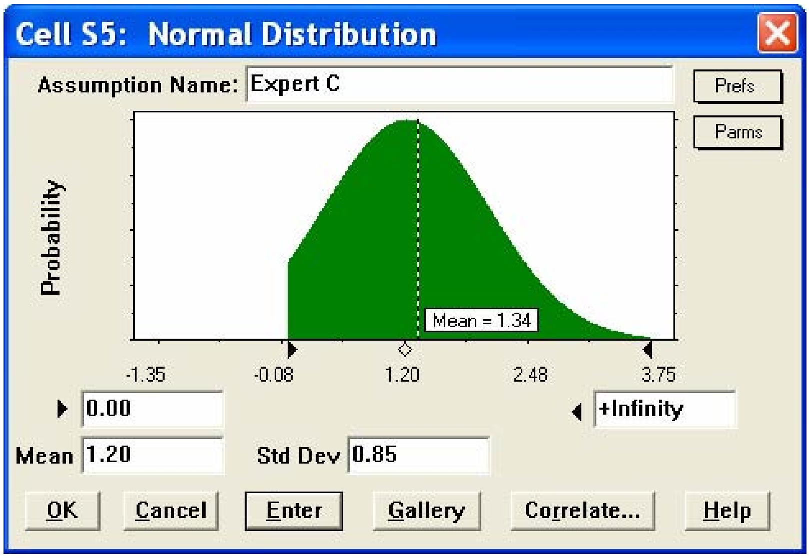
Cell D35: Custom Distribution

Assumption Name: Expert B 4 to 10 ug

Total Relative Prob. 1.00

In one special case, Expert E provided a normal distribution that implied a negative tail at the 2.5th percentile (the lower bound of a typical 95 percent confidence interval), but also specified a minimum value at zero. In this case, we treated the distribution as a truncated normal. In the case, the mean of the resulting incidence distribution will be shifted upwards relative to a full normal, to adjust for the mass of the distribution that would have been below zero (see Figure 6.3-6). Note that in the figure, the mean of the normal distribution specified by Expert C is 1.2, while the mean of the implied truncated normal will be 1.34.

Figure 6.3-6. Truncated Normal Distribution for Expert C



Cell S5: Normal Distribution

Assumption Name: Expert C

0.00

+Infinity

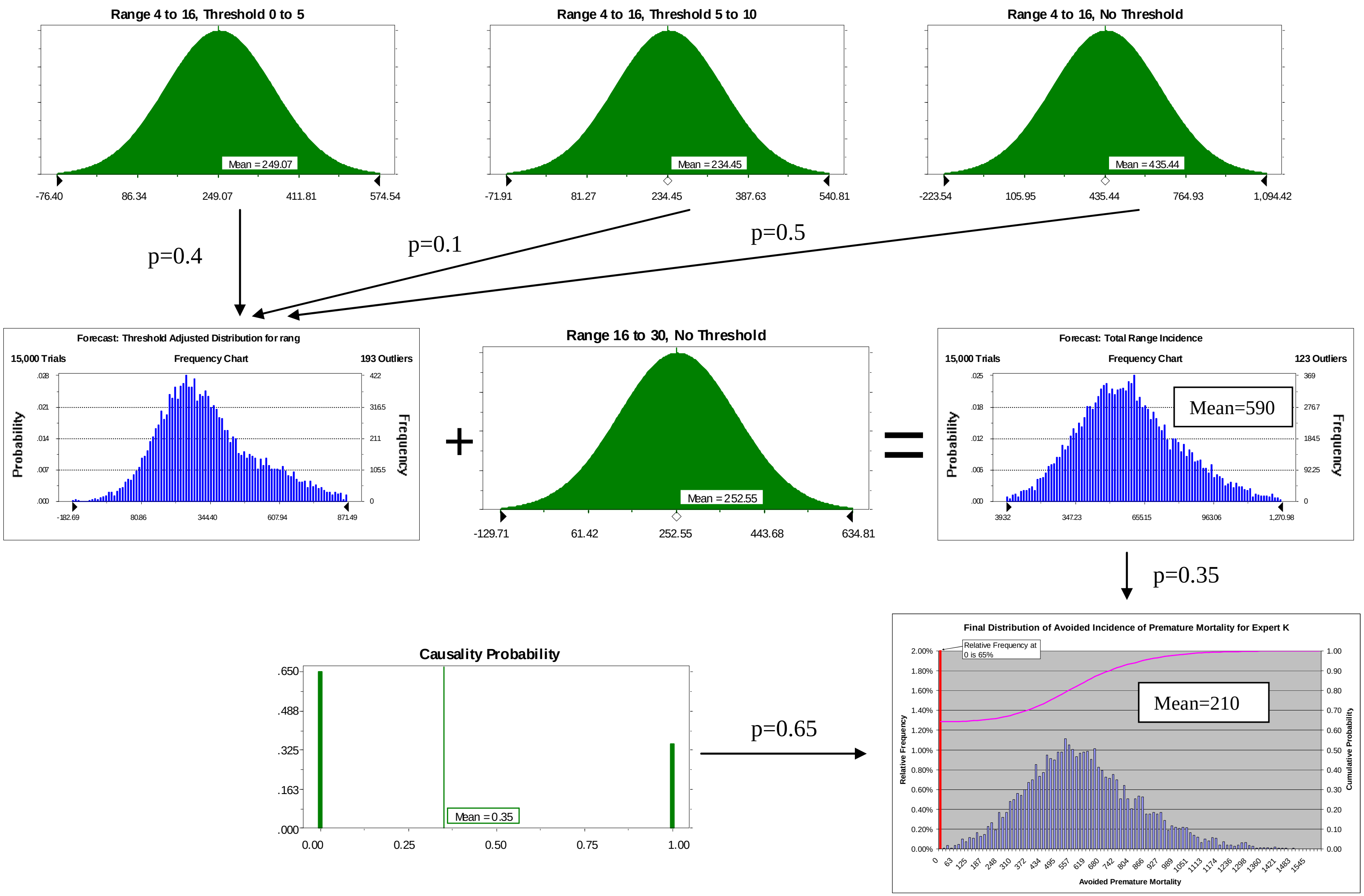
Mean 1.20

Std Dev 0.85

In some cases, experts included in their reported distributions the likelihood that the relationship between $PM_{2.5}$ and mortality was not causal, e.g., that reducing $PM_{2.5}$ would not actually reduce the risk of premature death. In these cases, the distributions are unconditional, and included zero with some probability to reflect views on less than certain causality. In most cases, the experts chose to specify a conditional distribution, such that the distribution of the effect estimate is conditional on there being a causal relationship. In these cases, the final estimated distribution of avoided incidence of premature mortality will be the expected value of the unconditional distribution. In practice, we implement this by estimating each expert's conditional distribution and then, using Monte Carlo sampling, construct an unconditional distribution using the expert's reported probability of a causal relationship. To illustrate how these various components of an expert's results are combined to produce an estimate of the distribution of reduced mortality associated with a reduction in ambient $PM_{2.5}$, we provide an example calculation for Expert K. This example calculation is graphically displayed in Figure 6.3-7. In Figure 6.3-7, the initial application of Expert K's conditional concentration-response functions provides 3 distributions associated with reductions in $PM_{2.5}$ concentrations in the range of starting concentrations from 4 to 16 $\mu g/m^3$. These distributions are assigned weights based on the expert's judgments about the likelihood of a threshold existing in the ranges 0 to 5, 5 to 10, or not at all. These weights are used to develop a new distribution for the change in mortality for starting concentrations between 4 and 16. These are then added to the distribution of the change in mortality associated with reductions in $PM_{2.5}$ in the range of starting concentrations from 16 to 30 $\mu g/m^3$. This gives an overall distribution of reductions in mortality for the full range of starting concentrations, conditional on the existence of a causal relationship. This conditional distribution is then combined with the expert's judgment about causality (35 percent likelihood of a causal relationship), to derive the unconditional distribution of changes in mortality, which, as can be seen in the figure, is composed of a mass of probability at zero (reflecting the likelihood of no causal relationship), and a probability density function (PDF) over the remaining 35 percent of probability characterized by the conditional distribution. As expected, the unconditional

Figure 6.3-7. Example Calculations Expert K

Initial Distributions:



distribution has a mean change in mortality that is 35 percent of the mean of the conditional distribution.

$PM_{2.5}$-Related Infant Mortality. Recently published studies have strengthened the case for an association between PM exposure and respiratory inflammation and infection leading to premature mortality in children under 5 years of age. Specifically, the SAB-HES noted the release of the WHO Global Burden of Disease Study focusing on ambient air, which cites several recently published time-series studies relating daily PM exposure to mortality in children (U.S. EPA-SAB, 2004b). The SAB-HES also cites the study by Belanger et al. (2003) as corroborating findings linking PM exposure to increased respiratory inflammation and infections in children. Recently, a study by Chay and Greenstone (2003) found that reductions in TSP caused by the recession of 1981–1982 were related to reductions in infant mortality at the county level. With regard to the cohort study conducted by Woodruff et al. (1997), the SAB-HES notes several strengths of the study, including the use of a larger cohort drawn from a large number of metropolitan areas and efforts to control for a variety of individual risk factors in infants (e.g., maternal educational level, maternal ethnicity, parental marital status, and maternal smoking status). Based on these findings, the SAB-HES recommends that EPA incorporate infant mortality into the primary benefits estimate and that infant mortality be evaluated using an impact function developed from the Woodruff et al. (1997) study (U.S. EPA-SAB, 2004b). A more recent study by Woodruff et al. (2006) continues to find associations between $PM_{2.5}$ and infant mortality. The study also found the most significant relationships with respiratory-related causes of death. We have not yet sought comment from the SAB on this more recent study and as such continue to rely on the earlier 1997 analysis.

Chronic Bronchitis. CB is characterized by mucus in the lungs and a persistent wet cough for at least 3 months a year for several years in a row. CB affects an estimated 5% of the U.S. population (American Lung Association, 1999). A limited number of studies have estimated the impact of air pollution on new incidences of CB. Schwartz (1993) and Abbey et al. (1995) provide evidence that long-term PM exposure gives rise to the development of CB in the United States. Because the proposed 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 CB.

Nonfatal Myocardial Infarctions (heart attacks). Nonfatal heart attacks have been linked with short-term exposures to $PM_{2.5}$ in the United States (Peters et al., 2001) and other countries (Poloniecki et al., 1997). We used a recent study by Peters et al. (2001) as the basis for the impact function estimating the relationship between $PM_{2.5}$ and nonfatal heart attacks. A more recent study by Zanobetti and Schwartz (2005) used a similar method to Peters et al. (2001), but focused on adults 65 and older, and used PM10 as the PM indicator. They found a significant relationship between nonfatal heart attacks and PM10, although the magnitude of the effect was much lower than Peters et al. This may reflect the use of PM10, the more limited age range, or the less precise diagnosis of heart attack used in defining the outcome measure. Other studies, such as Domenici et al. (2006), Samet et al. (2000), and Moolgavkar (2000), show a consistent relationship between all cardiovascular hospital admissions, including those for nonfatal heart attacks, and PM. Given the lasting impact of a heart attack on long-term health costs and earnings, we provide a separate estimate for nonfatal heart attacks. The estimate used in the analysis of the proposed standards is based on the single available U.S. $PM_{2.5}$ effect estimate from Peters et al. (2001). 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 United States. 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 are consistent with an increased risk of heart attacks.

Hospital and Emergency Room Admissions. Because of 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 use pooled impact functions based on the results of a number of studies. In addition, some studies have examined the relationship between air pollution and emergency room visits. Since most emergency room visits do not result in an admission to the hospital (the majority of people going to the emergency room are treated and return home), we treat hospital admissions and emergency room visits separately, taking account of the fraction of emergency room visits that are admitted to the hospital.

The two main groups of hospital admissions estimated in this analysis are respiratory admissions and cardiovascular admissions. There is not much evidence linking PM with other types of hospital admissions. The only type of emergency room visits that have been consistently linked to PM in the United States are asthma-related visits.

To estimate avoided incidences of $PM_{2.5}$ related cardiovascular hospital admissions in populations aged 65 and older, we use effect estimates from studies by Moolgavkar (2003) and Ito (2003). However, only Moolgavkar (2000) provided a separate effect estimate for populations 20 to 64.[R] Total cardiovascular hospital admissions are thus the sum of the pooled estimates from Moolgavkar (2003) and Ito (2003) for populations over 65 and the Moolgavkar (2000) based impacts for populations aged 20 to 64. Cardiovascular hospital admissions include admissions for myocardial infarctions. To avoid double-counting benefits from reductions in myocardial infarctions when applying the impact function for cardiovascular hospital admissions, we first adjusted the baseline cardiovascular hospital admissions to remove admissions for myocardial infarctions.

To estimate total avoided incidences of respiratory hospital admissions, we used impact functions for several respiratory causes, including chronic obstructive pulmonary disease

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[R] Note that the Moolgavkar (2000) study has not been updated to reflect the more stringent GAM convergence criteria. However, given that no other estimates are available for this age group, we chose to use the existing study. Updates have been provided for the 65 and older population, and showed little difference. Given the very small (<5%) difference in the effect estimates for people 65 and older with cardiovascular hospital admissions between the original and reanalyzed results, we do not expect the difference in the effect estimates for the 20 to 64 population to differ significantly. As such, the choice to use the earlier, uncorrected analysis will likely not introduce much bias.

(COPD), pneumonia, and asthma. As with cardiovascular admissions, additional published studies show a statistically significant relationship between PM_{10} and respiratory hospital admissions. We used only those focusing on $PM_{2.5}$. Both Moolgavkar (2000) and Ito (2003) provide effect estimates for COPD in populations over 65, allowing us to pool the impact functions for this group. Only Moolgavkar (2000) provides a separate effect estimate 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 Ito (2003) estimated pneumonia and only for the population 65 and older. In addition, Sheppard (2003) provided an effect estimate for asthma hospital admissions for populations under age 65. Total avoided incidence 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 effect estimate from 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 PM_{10} rather than $PM_{2.5}$. We selected the Norris et al. (1999) effect estimate 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 $PM_{2.5}$ on asthma emergency room visits in populations under 65, although there may still be significant impacts in the adult population under 65.

Acute Health Events and Work Loss Days. As indicated in Table 6.1-2, in addition to mortality, chronic illness, and hospital admissions, a number of acute health effects not requiring hospitalization are associated with exposure to ambient levels of PM. The sources for the effect estimates used to quantify these effects are described below.

Around 4 percent of U.S. children between the ages of 5 and 17 experience episodes of acute bronchitis annually (American Lung Association, 2002c). 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,[S] with the exception of cough, most acute bronchitis symptoms abate within 7 to 10 days. Incidence of episodes of acute bronchitis in children between the ages of 5 and 17 were estimated using an effect estimate developed from Dockery et al. (1996).

Incidences of lower respiratory symptoms (e.g., wheezing, deep cough) in children aged 7 to 14 were estimated using an effect estimate from Schwartz and Neas (2000).

Because asthmatics have greater sensitivity to stimuli (including air pollution), children with asthma can be more susceptible to a variety of upper respiratory symptoms (e.g., runny or stuffy nose; wet cough; and burning, aching, or red eyes). Research on the effects of air pollution on upper respiratory symptoms has thus focused on effects in asthmatics. Incidences of upper respiratory symptoms in asthmatic children aged 9 to 11 are estimated using an effect estimate developed from Pope et al. (1991).

[S] See http://www.nlm.nih.gov/medlineplus/ency/article/000124.htm, accessed January 2002.

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). Days of work lost due to $PM_{2.5}$ were estimated using an effect estimate developed from Ostro (1987).

MRADs 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 because of difficulty breathing or chest pain. The effect of $PM_{2.5}$ and ozone on MRAD was estimated using an effect estimate derived from Ostro and Rothschild (1989).

In analyzing the proposed standards, we have followed the SAB-HES recommendations regarding asthma exacerbations in developing the primary estimate. To prevent double-counting, we focused the estimation on asthma exacerbations occurring in children and excluded adults from the calculation.[T] Asthma exacerbations occurring in adults are assumed to be captured in the general population endpoints such as work loss days and MRADs. Consequently, if we had included an adult-specific asthma exacerbation estimate, we would likely double-count incidence for this endpoint. However, because the general population endpoints do not cover children (with regard to asthmatic effects), an analysis focused specifically on asthma exacerbations for children (6 to 18 years of age) could be conducted without concern for double-counting.

To characterize asthma exacerbations in children, we selected two studies (Ostro et al., 2001; Vedal et al., 1998) that followed panels of asthmatic children. Ostro et al. (2001) followed a group of 138 African-American children in Los Angeles for 13 weeks, recording daily occurrences of respiratory symptoms associated with asthma exacerbations (e.g., shortness of breath, wheeze, and cough). This study found a statistically significant association between $PM_{2.5}$, measured as a 12-hour average, and the daily prevalence of shortness of breath and wheeze endpoints. Although the association was not statistically significant for cough, the results were still positive and close to significance; consequently, we decided to include this

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[T] Estimating asthma exacerbations associated with air pollution exposures is difficult, due to concerns about double-counting of benefits. Concerns over double-counting stem from the fact that 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 is limited to asthmatic children, so this endpoint can be readily included in the calculation of total benefits. However, other endpoints, such as lower respiratory symptoms and MRADs, are estimated for the total population that includes asthmatics. Therefore, to simply add predictions of asthma-related symptoms generated for the population of asthmatics to these total population-based estimates could result in double-counting, especially if they evaluate similar endpoints. The SAB-HES, in commenting on the analytical blueprint for 812, acknowledged these challenges in evaluating asthmatic symptoms and appropriately adding them into the primary analysis (U.S. EPA-SAB, 2004b). However, despite these challenges, the SAB-HES recommends the addition of asthma-related symptoms (i.e., asthma exacerbations) to the primary analysis, provided that the studies use the panel study approach and that they have comparable design and baseline frequencies in both asthma prevalence and exacerbation rates. Note also, that the SAB-HES, while supporting the incorporation of asthma exacerbation estimates, does not believe that the association between ambient air pollution, including ozone and PM, and the new onset of asthma is sufficiently strong to support inclusion of this asthma-related endpoint in the primary estimate.

endpoint, along with shortness of breath and wheeze, in generating incidence estimates (see below). Vedal et al. (1998) followed a group of elementary school children, including 74 asthmatics, located on the west coast of Vancouver Island for 18 months including measurements of daily peak expiratory flow (PEF) and the tracking of respiratory symptoms (e.g., cough, phlegm, wheeze, chest tightness) through the use of daily diaries. Association between PM_{10} and respiratory symptoms for the asthmatic population was only reported for two endpoints: cough and PEF. Because it is difficult to translate PEF measures into clearly defined health endpoints that can be monetized, we only included the cough-related effect estimate from this study in quantifying asthma exacerbations. We employed the following pooling approach in combining estimates generated using effect estimates from the two studies to produce a single asthma exacerbation incidence estimate. First, we pooled the separate incidence estimates for shortness of breath, wheeze, and cough generated using effect estimates from the Ostro et al. study, because each of these endpoints is aimed at capturing the same overall endpoint (asthma exacerbations) and there could be overlap in their predictions. The pooled estimate from the Ostro et al. study is then pooled with the cough-related estimate generated using the Vedal study. The rationale for this second pooling step is similar to the first; both studies are attempting to quantify the same overall endpoint (asthma exacerbations).

Additional epidemiological studies are available for characterizing asthma-related health endpoints (the full list of epidemiological studies considered for modeling asthma-related incidence is presented in Table 6.3-6). However, based on recommendations from the SAB-HES, we decided not to use these additional studies in generating the primary estimate. In particular, the Yu et al. (2000) estimates show a much higher baseline incidence rate than other studies, which may lead to an overstatement of the expected impacts in the overall asthmatic population. The Whittemore and Korn (1980) study did not use a well-defined endpoint, instead focusing on a respondent-defined “asthma attack.” Other studies looked at respiratory symptoms in asthmatics but did not focus on specific exacerbations of asthma.

6.3.5.4 Treatment of Potential Thresholds in Health Impact Functions

Unless specifically noted, our premature mortality benefits estimates are based on an assumed cutpoint in the premature mortality concentration-response function at 10 $\mu g/m^3$, and an assumed cutpoint of 10 $\mu g/m^3$ for the concentration-response functions for morbidity associated with short term exposure to PM2.5. The 10 $\mu g/m^3$ threshold reflects comments from CASAC (U.S. EPA Science Advisory Board, 2005). To consider the impact of a threshold in the response function for the chronic mortality endpoint on the primary benefits estimates, we also constructed a sensitivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. In applying the cutpoints, we adjusted the mortality function slopes accordingly.[U] This sensitivity analysis allows us to determine the change (reduction) in avoided mortality cases and associated monetary benefits associated with

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[U] Note, that the adjustment to the mortality slopes was only done for the 10 $\mu g/m^3$, 12 $\mu g/m^3$, and 14 $\mu g/m^3$ cutpoints since the 7.5 $\mu g/m^3$ and background cutpoints are at or below the lowest measured exposure levels reported in the ACS cohort study, for the combined exposure dataset. See Appendix H for a complete discussion of the slope adjustment procedure.

alternative cutpoints. Five cutpoints (including the base case assumption) were included in this sensitivity analysis: (a) 14 $\mu g/m^3$ (assumes no impacts below the alternative annual NAAQS), (b) 12 $\mu g/m^3$ (c) 10 $\mu g/m^3$ (reflects comments from CASAC - 2005), (d) 7.5 $\mu g/m^3$ (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the ACS cohort study used as the basis for modeling chronic mortality) and (e) background or 3 $\mu g/m^3$ (reflects NRC recommendation to consider effects all the way to background).

Table 6.3-6. Studies Examining Health Impacts in the Asthmatic Population Evaluated for Use in the Benefits Analysis

Endpoint	Definition	Pollutant	Study	Study Population
Asthma Attack Indicators				
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	$PM_{2.5}$	Whittemore and Korn (1980)	Asthmatics, all ages

6.3.5.5 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 3%. To then to convert this relative change into a number of cases, the baseline incidence of the health effect is necessary. 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 (e.g., asthma). For both baseline incidence and prevalence data, we use age-specific rates where available. Impact 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, because of 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, we continue to use current incidence rates. The one exception is in the case of premature mortality. In this case, we have projected mortality rates such that future mortality rates are consistent with our projections of population growth (Abt Associates, 2005). Compared with previous analyses, this will result in a reduction in the mortality related impacts of air pollution in future years.

Table 6.3-7 summarizes the baseline incidence data and sources used in the benefits analysis. We use the most geographically disaggregated data available. For premature mortality, county-level data are available. For hospital admissions, regional rates are available. However, for all other endpoints, a single national incidence rate is used, due to a lack of more spatially disaggregated data. In these cases, 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.

Table 6.3-7: Baseline Incidence Rates and Population Prevalence Rates for Use in Impact Functions, General Population

Endpoint	Parameter	Rates	
		Value	Source[a]
Mortality	Daily or annual mortality rate	Age-, cause-, and county-specific rate	CDC Wonder (1996–1998)
Hospitalizations	Daily hospitalization rate	Age-, region-, and cause-specific rate	1999 NHDS public use data files[b]
Asthma ER Visits	Daily asthma ER visit rate	Age- and region-specific visit rate	2000 NHAMCS public use data files[c]; 1999 NHDS public use data files[b]
Chronic Bronchitis	Annual prevalence rate per person - Aged 18–44 - Aged 45–64 - Aged 65 and older	 0.0367 0.0505 0.0587	1999 NHIS (American Lung Association, 2002b, Table 4)
	Annual incidence rate per person	0.00378	Abbey et al. (1993, Table 3)
Nonfatal Myocardial Infarction (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[b]; adjusted by 0.93 for probability of surviving after 28 days (Rosamond et al., 1999)
Asthma Exacerbations	Incidence (and prevalence) among asthmatic African-American children - daily wheeze - daily cough - daily dyspnea	 0.076 (0.173) 0.067 (0.145) 0.037 (0.074)	Ostro et al. (2001)
	Prevalence among asthmatic children - daily wheeze - daily cough - daily dyspnea	 0.038 0.086 0.045	Vedal et al. (1998)
Acute Bronchitis	Annual bronchitis incidence rate, children	0.043	American Lung Association (2002c, Table 11)
Lower Respiratory Symptoms	Daily lower respiratory symptom incidence among children[d]	0.0012	Schwartz et al. (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) - Aged 18–24 - Aged 25–44 - Aged 45–64	 0.00540 0.00678 0.00492	1996 HIS (Adams, Hendershot, and Marano, 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)

[a] 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.

[b] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHDS/.

[c] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHAMCS/.

[d] Lower respiratory symptoms are defined as two or more of the following: cough, chest pain, phlegm, and wheeze.

Baseline age, cause, and county-specific mortality rates were obtained from the U.S. Centers for Disease Control and Prevention (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 3 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- to 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.

To estimate age- and county-specific mortality rates in years 2000 through 2020, we calculated adjustment factors, based on a series of Census Bureau projected national mortality rates, to adjust the CDC Wonder age- and county-specific mortality rates in 1996-1998 to corresponding rates for each future year. For the analysis year 2020, these adjustment factors ranged across age categories from 0.76 to 0.86

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 6.3-7 lists the baseline incidence rates and their sources for asthma symptom endpoints. Table 6.3-8 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. However, it should be noted that current trends in asthma prevalence do not lead us to expect that asthma prevalence rates will be more than 4% overall in 2020, or that large changes will occur in asthma prevalence rates for individual age categories (Mansfield et al., 2005).

Table 6.3-8 Asthma Prevalence Rates Used to Estimate Asthmatic Populations in Impact Functions

Population Group	Asthma Prevalence Rates	
	Value	Source
All Ages	0.0386	American Lung Association (2002a, Table 7)—based on 1999 HIS
< 18	0.0527	American Lung Association (2002a, Table 7)—based on 1999 HIS
5–17	0.0567	American Lung Association (2002a, Table 7)—based on 1999 HIS
18–44	0.0371	American Lung Association (2002a, Table 7)—based on 1999 HIS
45–64	0.0333	American Lung Association (2002a, Table 7)—based on 1999 HIS
65+	0.0221	American Lung Association (2002a, Table 7)—based on 1999 HIS
Male, 27+	0.021	2000 HIS public use data files[a]
African American, 5 to 17	0.0726	American Lung Association (2002a, Table 9)—based on 1999 HIS
African American, <18	0.0735	American Lung Association (2002a, Table 9)—based on 1999 HIS

[a] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHIS/2000/.

6.3.5.6 Selecting Unit Values for Monetizing Health Endpoints

The appropriate economic value for 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 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 COI estimates generally (although not in every case) 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 6.3-9 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 out to 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. A discussion of the valuation methods for premature mortality and CB is provided here because of the relative importance of these effects. Discussions of the methods used to value nonfatal myocardial infarctions (heart attacks) and school absence days are provided because these endpoints have only recently been added to the analysis 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 6.3-9. COI estimates are converted to constant 1999 dollar equivalents using the medical CPI.

Valuing Reductions in Premature Mortality Risk. Following the advice of the EEAC of the SAB, EPA currently uses the VSL approach when calculating mortality benefits, because we believe this calculation provides the most reasonable single estimate of an individual’s willingness to trade off money for reductions in mortality risk (EPA, 2000a). The VSL approach is a summary measure for the value of small changes in mortality risk experienced by a large number of people. The mean value of avoiding one statistical death is assumed to be $5.5 million in 1999 dollars. This represents a central value consistent with the range of values suggested by recent meta-analyses of the wage-risk VSL literature. The distribution of VSL is characterized by a confidence interval from $1 to $10 million, based on two meta-analyses of the wage-risk VSL literature. The $1 million lower confidence limit represents the lower end of the interquartile range from the Mrozek and Taylor (2002) meta-analysis. The $10 million upper confidence limit represents the upper end of the interquartile range from the Viscusi and Aldy (2003) meta-analysis. The mean estimate of $5.5 million is consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006) meta-analysis. Because the majority of the studies in these meta-analyses are based on datasets from the early 1990s or previous decades, we continue to assume that the VSL estimates provided by those meta-analyses are in 1990 income equivalents. Future research might provide income-adjusted VSL values for individual studies that can be incorporated into the meta-analyses. This would allow for a more reliable base-year estimate for use in adjusting VSL for aggregate changes in income over time.

As indicated in the previous section on quantification of premature mortality benefits, we assumed for this analysis that some of the incidences of premature mortality related to PM exposures occur in a distributed fashion over the 20 years following exposure. To take this into account in the valuation of reductions in premature mortality, we applied an annual 3% discount rate to the value of premature mortality occurring in future years.[V]

[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% 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% 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* (EPA, 2000b).

Table 6.3-9. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a]

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Premature Mortality (Value of a Statistical Life): $PM_{2.5}$-related	$5,500,000	$6,600,000	$6,800,000	Point estimate is the mean of a normal distribution with a 95 percent confidence interval between $1 and $10 million. Confidence interval is based on two meta-analyses of the wage-risk VSL literature: $1 million represents the lower end of the interquartile range from the Mrozek and Taylor (2002)[27] meta-analysis and $10 million represents the upper end of the interquartile range from the Viscusi and Aldy (2003)[28] meta-analysis. The VSL represents the value of a small change in mortality risk aggregated over the affected population.
Chronic Bronchitis (CB)	$340,000	$420,000	$430,000	Point estimate 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][29]) 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.
Nonfatal Myocardial Infarction (heart attack)				Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990).[30] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[31] and Wittels et al. (1990).[32] Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years 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-year 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	

(continued)

Table 6.3-9. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
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)[33] (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).
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)[34] and (2) $260.67, from Stanford et al. (1999).[35]

(continued)

Table 6.3-9. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
Respiratory Ailments Not Requiring Hospitalization				
Upper Respiratory Symptoms (URS)	$25	$27	$27	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven 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)[36] 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 seven different types of URS.
Lower Respiratory Symptoms (LRS)	$16	$17	$17	Combinations of the four 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.
Asthma Exacerbations	$42	$45	$45	Asthma exacerbations are valued at $42 per incidence, based on the mean of average WTP estimates for the four severity definitions of a “bad asthma day,” described in Rowe and Chestnut (1986).[37] This study surveyed asthmatics to estimate WTP for avoidance of a “bad asthma day,” as defined by the subjects. For purposes of valuation, an asthma attack is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study.
Acute Bronchitis	$360	$380	$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).[38]

(continued)

Table 6.3-9. Unit Values Used for Economic Valuation of Health Endpoints (2000$)[a] (continued)

Health Endpoint	Central Estimate of Value Per Statistical Incidence			Derivation of Estimates
	1990 Income Level	2020 Income Level[b]	2030 Income Level[b]	
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.
Minor Restricted Activity Days (MRADs)	$51	$54	$55	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[39]

[a] Although the unit values presented in this table are in year 2000 dollars, all monetized annual benefit estimates associated with the proposed standards have been inflated to reflect values in year 2005 dollars. We use the Consumer Price Indexes to adjust both WTP- and COI-based benefits estimates to 2005 dollars from 2000 dollars.[40] For WTP-based estimates, we use an inflation factor of 1.13 based on the CPI-U for “all items.” For COI-based estimates, we use an inflation factor of 1.24 based on the CPI-U for medical care.

[b] 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. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For a complete discussion of how these adjustment factors were derived, we refer the reader to Chapter 9 of the CAND regulatory impact analysis (EPA, 2004). Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

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 economics and public policy analysis community. EPA strives to use the best economic science in its analyses. Given the mixed theoretical finding and empirical evidence regarding adjustments to VSL for risk and population characteristics, we use a single VSL for all reductions in mortality risk.

Although there are several differences between the labor market studies EPA uses to derive a VSL estimate and the PM air pollution context addressed here, those differences in the affected populations and the nature of the risks imply both upward and downward adjustments. Table 6.3-10 lists some of these differences and the expected effect on the VSL estimate for air pollution-related mortality. In the absence of a comprehensive and balanced set of adjustment factors, EPA believes it is reasonable to continue to use the $5.5 million value while acknowledging the significant limitations and uncertainties in the available literature.

Table 6.3-10. 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

The SAB-EEAC has reviewed many potential VSL adjustments and the state of the economics literature. The SAB-EEAC advised EPA to “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” (U.S. EPA, 2000a). In developing our primary estimate of the benefits of premature mortality reductions, we have followed this advice and discounted over the lag period between exposure and premature mortality.

Uncertainties Specific to Premature Mortality Valuation. The economic benefits associated with $PM_{2.5}$-related premature mortality are the largest category of monetized benefits associated with the proposed standards. 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).[W] Because of the uncertainty in estimates of the value of premature mortality

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[W] This conclusion was based on a assessment of uncertainty based on statistical error in epidemiological effect estimates and economic valuation estimates. Additional sources of model error such as those examined in the PM 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 economics 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. An ideal benefits estimate of mortality risk reduction would reflect these human characteristics, in addition to an individual's 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 depend 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 VSL approach.

Other uncertainties specific to premature mortality valuation include the following:

- *Across-study variation:* There is considerable uncertainty as to whether the available literature on VSL provides adequate estimates of the VSL saved by air pollution reduction. Although there is considerable variation in the analytical designs and data used in the existing literature, 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 hedonic wage approach. Certain characteristics of both the

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mortality expert elicitation may result in different conclusions about the relative contribution of sources of uncertainty.

population affected and the mortality risk facing that population are believed to affect the average WTP to reduce the risk. The appropriateness of a distribution of WTP based on the current VSL literature 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 the extent to which the risks being valued are similar and 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 VSL from the wage-risk studies to the context of the proposed standards 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 provides a result 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 10 times the risk reduction valued in the study). Under the assumption of linearity, the estimate of the VSL 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 job-related mortality risks may differ in several ways 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. Some evidence suggests 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 and Stamland, 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 trade-off 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.

- *Baseline risk and age:* Recent research (Smith, Pattanayak, and Van Houtven, 2006) finds that because individuals reevaluate their baseline risk of death as they age, the marginal value of risk reductions does not decline with age as predicted by some lifetime consumption models. This research supports findings in recent stated preference studies that suggest only small reductions in the value of mortality risk reductions with increasing age.

Valuing Reductions in the Risk of Chronic Bronchitis. The best available estimate of WTP to avoid a case of CB comes from Viscusi, Magat, and Huber (1991). The Viscusi, Magat, and Huber 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, Magat, and Huber (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 the Nonroad Diesel rulemaking (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: the WTP to avoid a case of severe CB, as described by Viscusi, Magat, and Huber; the severity level of an average pollution-related case of CB (relative to that of the case described by Viscusi, Magat, and Huber); and 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.

Valuing Reductions in Nonfatal Myocardial Infarctions (Heart Attacks). The Agency has recently incorporated into its analyses the impact of air pollution on the expected number of nonfatal heart attacks, although it has examined the impact of reductions in other related cardiovascular endpoints. We were not able to identify a suitable WTP value for reductions in the risk of nonfatal heart attacks. Instead, we use a COI 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 a myocardial infarction 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 3% discount rate, we estimated a present discounted value in lost earnings (in 2000$) over 5 years due to a myocardial infarction 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 7% discount rate are $7,855, $11,578, and $66,920, respectively. Cropper and Krupnick (1990) do not provide lost earnings estimates for populations under 25 or over 65. As such, we do not include lost earnings in the cost estimates for these age groups.

We found three possible sources in the literature of estimates of the direct medical costs of myocardial infarction:

- Wittels et al. (1990) estimated expected total medical costs of myocardial infarction 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 myocardial infarction 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 for myocardial infarction may have decreased from 1983 to the present. The average length of stay for ICD code 410 (myocardial infarction) in the year-2000 Agency for Healthcare Research and Quality (AHRQ) HCUP database is 5.5 days. However, this may include patients who died in the hospital (not included among our nonfatal myocardial infarction cases), whose length of stay was therefore substantially shorter than it would be if they had not died.

- Eisenstein et al. (2001) estimated 10-year costs of $44,663 in 1997$, or $49,651 in 2000$ for myocardial infarction 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 myocardial infarction 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 10-year period.

In summary, the three different studies provided significantly different values (see Table 6.3-11).

Table 6.3-11. 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[a]	5
Russell et al. (1998)	$22,331[b]	5
Eisenstein et al. (2001)	$49,651[b]	10
Russell et al. (1998)	$27,242[b]	10

[a] Wittels et al. (1990) did not appear to discount costs incurred in future years.

[b] Using a 3% discount rate. Discounted values as reported in the study.

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 used 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 used a simple average of the two 5-year estimates, or $65,902, and added it to the 5-year opportunity cost estimate. The resulting estimates are given in Table 6.3-12.

Table 6.3-12. Estimated Costs Over a 5-Year Period (in 2000$) of a Nonfatal Myocardial Infarction

Age Group	Opportunity Cost	Medical Cost[a]	Total Cost
0–24	$0	$65,902	$65,902
25–44	$8,774[b]	$65,902	$74,676
45–54	$12,253[b]	$65,902	$78,834
55–65	$70,619[b]	$65,902	$140,649
> 65	$0	$65,902	$65,902

[a] An average of the 5-year costs estimated by Wittels et al. (1990) and Russell et al. (1998).

[b] From Cropper and Krupnick (1990), using a 3% discount rate.

6.3.6 Human Welfare Impact Assessment

Ozone, PM and their precursor emissions 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 ozone, PM, NO_x, and SO_2 list numerous physical and ecological effects known to be linked to ambient concentrations of these pollutants (U.S. EPA, 2005; 1993). This section describes individual effects and how we quantify and monetize them. These effects include changes in nitrogen and sulfate deposition, and visibility.

6.3.6.1 Visibility Benefits

Changes in the level of ambient $PM_{2.5}$ caused by the reduction in emissions associated with the proposed standards will change the level of visibility throughout the United States. 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 Great Smoky Mountains National Park. This section discusses the measurement of the economic benefits of improved 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, 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, the *deciview*, based directly on the degree of measured light absorption. Deciviews are standardized for a reference distance in such a way that one deciview corresponds to a change of about 10% 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 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 use values and nonuse values. Use values include the aesthetic benefits of better visibility, improved road and air safety, and enhanced recreation in activities like hunting and birdwatching. Nonuse values are based on people's beliefs that the environment ought to exist free of human-induced haze. Nonuse values may be more important 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

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[X] A change of less than 10% 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% 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 that, when considered together, amount to perceptible changes in visibility.

[Y] The Clean Air Act designates 156 national parks and wilderness areas as Class I areas for visibility protection.

residential visibility, while all households in the United States 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). Although there are a number of other studies in the literature, they were conducted in the early 1980s and did not use methods that are considered defensible by current standards. Both the Chestnut and Rowe and McClelland et al. studies use the CV 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 (U.S. EPA-SAB, 1999). Residential visibility benefits are not calculated for this analysis.

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 WTP 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 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 United States. We can infer the value of visibility changes in the other Class I areas by transferring

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[Z] For details of the visibility estimates discussed in this chapter, please refer to the Benefits TSD for the Nonroad Diesel rulemaking (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, p. 13). 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).

values of visibility changes at Class I areas in the study regions. 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 the Nonroad Diesel rulemaking (Abt Associates, 2003).

The Chestnut and Rowe study, although representing the best available estimates, has a number of limitations. These include the following:

- The age of the study (late 1980s) will increase the uncertainty about the correspondence of the estimated values to those that might be provided by current or future populations.
- The survey focused only on populations in five states, so the application of the estimated values to populations outside those states requires that preferences of populations in the five surveyed states be similar to those of nonsurveyed states.
- There is an inherent difficulty in separating values expressed for visibility improvements from an overall value for improved air quality. The Chestnut and Rowe study attempted to control for this by informing respondents that "other households are being asked about visibility, human health, and vegetation protections in urban areas and at national parks in other regions." However, most of the respondents did not feel that they were able to segregate visibility at national parks entirely from residential visibility and health effects.
- It is not clear exactly what visibility improvements the respondents to the Chestnut and Rowe survey were valuing. For the purpose of the benefits analysis for this rule, EPA assumed that respondents provided values for changes in annual average visibility. Because most policies will result in a shift in the distribution of visibility (usually affecting the worst days more than the best days), the annual average may not be the most relevant metric for policy analysis.
- The WTP question asked about changes in average visibility. However, the survey respondents were shown photographs of only summertime conditions, when visibility is generally at its worst. It is possible that the respondents believed those visibility conditions held year-round, in which case they would have been valuing much larger overall improvements in visibility than what otherwise would be the case.
- The survey did not include reminders of possible substitutes (e.g., visibility at other parks) or budget constraints. These reminders are considered to be best practice for stated preference surveys.
- The Chestnut and Rowe survey focused on visibility improvements in and around national parks and wilderness areas. The survey also focused on visibility improvements of national parks in the southwest United States. Given that national parks and wilderness areas exhibit unique characteristics, it is not clear whether the WTP estimate obtained from Chestnut and Rowe can be transferred to other national parks and wilderness areas, without introducing additional uncertainty.

In general, the survey design and implementation reflect the period in which the survey was conducted. Since that time, many improvements to the stated preference methodology have been developed. As future survey efforts are completed, EPA will incorporate values for visibility improvements reflecting the improved survey designs.

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 reductions in precursor emissions associated with the proposed standards. A general WTP 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 proposed standards. 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% increase in income is associated with a 0.9% 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 associated with the proposed standards would be $150 million in 2020 and $400 million in 2030. These values includes the value to households living in the same states as the Class I areas as well as values for all households in the United States living outside the states containing the Class I areas, and the value accounts for growth in real income.

One major source of uncertainty for the visibility benefits estimate is the benefits transfer process used. Judgments used to choose the functional form and key parameters of the estimating equation for WTP 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.

6.3.6.2 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" (EPA, 2006).[41] Changes in ground-level ozone are expected to improve crop and forest yields throughout the country as a result of the proposed standards.

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. Because of resource limitations, we are unable to provide agricultural or forestry benefits estimates for the proposed standards.

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 United States."[42] In addition, economic studies have shown a relationship between observed ozone levels and crop yields.[43]

Ozone also has been shown conclusively to cause discernible injury to forest trees (EPA, 1996; Fox and Mickler, 1996).[68,44] 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. Because of resource limitations, we were not able to quantify such impacts for this analysis.

NO_x emission reductions will 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 oversaturation 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.

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 the deposition of nitrogen could have negative effects on forest and vegetation growth in ecosystems where nitrogen is a limiting factor (EPA, 1993).

On the other hand, there is evidence that forest ecosystems in some areas of the United States are nitrogen saturated (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.

6.3.6.3 Benefits from Reductions in Materials Damage

The proposed standards 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. Particulate matter also has 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 benefits 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 1970s) are too out of date to provide a reliable estimate of current household soiling damages (U.S. EPA, 1998).

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.

6.3.6.4 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. 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 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 functions and on estimates of the value of environmental responses. Because neither appropriate 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 stated preference 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.

6.4 Benefits Analysis Results for the Proposed Standards

Applying the impact and valuation functions described previously in this chapter to the estimated changes in $PM_{2.5}$ associated with the proposed standards results in estimates of the changes in health effects (e.g., premature mortalities, cases, admissions) and the associated monetary values for those changes. Estimates of physical health impacts are presented in Table 6.4-1. Monetized values for those health endpoints are presented in Table 6.4-2, along with total aggregate monetized benefits. All of the monetary benefits are in constant-year 2005 dollars. For each endpoint and total benefits, we provide both the mean estimate and the 95% confidence interval.

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$-related health and welfare effects could be quantified or monetized. The monetized value of all of these unquantified effects is represented by adding an unknown "B" to the aggregate total. The estimate of total monetized health benefits of the proposed standards is thus equal to the subset of monetized $PM_{2.5}$- related health benefits plus B, the sum of the nonmonetized health and welfare benefits.

Total monetized benefits are dominated by benefits of mortality risk reductions. We provide results based on concentration response functions from the American Cancer Society Study (ACS), Six-Cities, and Expert Elicitation to give an indication of the sensitivity of the benefits estimates to alternative assumptions. Following the recommendations of the NRC report (NRC, 2002), we identify those estimates which are based on empirical data, and those which are based on expert judgments. EPA intends to ask its Science Advisory Board to evaluation how EPA has incorporated expert elicitation results into the benefits analysis, and the extent to which they find the presentation in this RIA responsive to the NRC (2002) guidance to incorporate uncertainty into the main analysis and further, whether the agency should move toward presenting a central estimate with uncertainty bounds or continue to provide separate estimates for each of the 12 experts as well as from the ACS and Six Cities studies, and if so, the appropriateness of using Laden et al 2006, the most recently published update, as the estimate for the Six Cities based model.

Using the ACS and Six-Cities results, we estimate that the proposed standards would result in between 570 and 1,300 cases of avoided $PM_{2.5}$-related premature deaths annually in 2020 and between 1,500 and 3,400 avoided premature deaths annually in 2030. Note that in the case of the premature mortality estimates derived from the expert elicitation, we report the 95%

credible interval, which encompasses a broader representation of uncertainty relative to the statistical confidence intervals provided for the effect estimates derived from the epidemiology literature.

As noted above, we provide two approaches to estimating avoided premature mortality associated with $PM_{2.5}$ exposure. Our estimate of total monetized benefits in 2020 for the proposed standards, using the ACS and Six-Cities PM mortality studies, is between \$4.4 billion and \$9.2 billion, assuming a 3 percent discount rate (or \$4.0 and \$8.3 billion assuming a 7 percent discount rate). In 2030, the monetized benefits are estimated to be between \$12 billion and \$25 billion (or \$11 and \$23 billion assuming a 7 percent discount rate). The monetized benefit associated with reductions in the risk of $PM_{2.5}$-related premature mortality is over 90 percent of total monetized health benefits, in part because we are unable to quantify a number benefits categories (see Table 6.1-2). These unquantified benefits may be substantial, although their magnitude is highly uncertain. Our estimate of total monetized benefits based on the expert elicitation is between \$1.7 billion and \$12 billion, assuming a 3 percent discount rate (or \$1.6 and \$11 billion assuming a 7 percent discount rate). In 2030, the monetized benefits are estimated to be between \$4.6 billion and \$33 billion (or \$4.3 and \$30 billion assuming a 7 percent discount rate).

The next largest benefit is for reductions in chronic illness (chronic bronchitis and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. 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 over 100 times more work loss days than PM-related premature mortalities (based on the ACS study), 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 willingness-to-pay (e.g., cost-of-illness). As such, the true value of these effects may be higher than that reported in Table 6.4-2.

Following these tables, we also provide a more comprehensive graphical presentation of the distributions of incidence generated using the available information from empirical studies and expert elicitation. Figures 6.4-1 and 6.4-2 present box plots of the distributions of the reduction in $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with the ACS study (Pope et al., 2002) and the Six-cities study (Laden et al., 2006). The distributions are depicted as box plots with the diamond symbol (◆) showing the mean, the dash (–) showing the median (50th percentile), the box defining the interquartile range (bounded by the 25th and 75th percentiles), and the whiskers defining the 90% confidence interval (bounded by the 5th and 95th percentiles of the distribution). The mean and 90% confidence interval for each separate estimate of mortality is also provided in Tables 6.4-3 and 6.4-4.

To consider the impact of a threshold in the response function for the chronic mortality endpoint, we have constructed a sensitivity analysis by assigning different cutpoints below which changes in $PM_{2.5}$ are assumed to have no impact on premature mortality. In applying the cutpoints, we have adjusted the mortality function slopes accordingly.[BB] Five cutpoints (including the base case assumption) were included in the sensitivity analysis: (a) 14 µg/m3 (assumes no impacts below the alternative annual NAAQS), (b) 12 µg/m3 (c) 10 µg/m3 (reflects comments from CASAC, 2005) [45], (d) 7.5 µg/m3 (reflects recommendations from SAB-HES to consider estimating mortality benefits down to the lowest exposure levels considered in the Pope 2002 study used as the basis for modeling chronic mortality) [46] and (e) background or 3 µg/m3 (reflects NRC recommendation to consider effects all the way to background).[47] We repeat this sensitivity analysis for the RIA of the proposed standards, the results of which can be found in Table 6.4-5.

A sensitivity analysis such as this can be difficult to interpret, because when a threshold above the lowest observed level of $PM_{2.5}$ in the underlying epidemiology study (Pope et al., 2002) is assumed, the slope of the concentration-response function above that level must be adjusted upwards to account for the assumed threshold.[CC] Depending on the amount of slope adjustment and the proportion of the population exposed above the assumed threshold, the estimated mortality impact can either be lower (if most of the exposures occur below the threshold) or higher (if most of the exposures occur above the threshold). To demonstrate this possibility, we present an example from the proposed PM NAAQS RIA. In its examination of the benefits of attaining alternative PM NAAQS in Chicago,[DD] the analysis found that, because annual mean levels are generally higher in Chicago, there was a two-part pattern to the relationship between assumed threshold and mortality impacts. As the threshold increased from background to 7.5 $\mu g/m^3$, the mortality impact fell (because there is no slope adjustment). However, at an assumed threshold of 10 $\mu g/m^3$, estimated mortality impacts actually increased, because the populations exposed above 10 $\mu g/m^3$ were assumed to have a larger response to particulate matter reductions (due to the increased slope above the assumed threshold). And finally, mortality impacts again fell to zero if a 15 $\mu g/m^3$ threshold was assumed, because these impacts were measured incremental to attainment of the current standard.

[BB] Note that this analysis only adjusted the mortality slopes for the 10 $\mu g/m^3$, 12 $\mu g/m^3$ and 14 $\mu g/m^3$ cutpoints since the 7.5 $\mu g/m^3$ and background cutpoints were at or below the lowest measured exposure levels reported in the Pope et al. (2002) study for the combined exposure dataset.

[CC] See NAS (2002)[87] and CASAC (2005)[85] for discussions of this issue.

[DD] See the proposed PM NAAQS RIA (2005),[67] Appendix A, pp. A63-A64.

Our analysis of the proposed standards also demonstrates this possibility. In Table 6.4-5, we can see that there is a two-part pattern to the relationship between assumed threshold and mortality impacts. As the threshold increases from background to 7.5 μg/m3, we see no difference in mortality impact (because all changes in PM appear to occur above a 7.5 μg/m3 threshold and there is no slope adjustment). At a threshold of 10 μg/m3, however, estimated mortality impacts actually increase, because the populations exposed above 10 μg/m3 are assumed to have a larger response to particulate matter reductions (due to the increased slope above the assumed threshold). Finally, like the PM NAAQS example, mortality impacts again fall as the threshold is increased.

Table 6.4-1. Estimated Reduction in Incidence of Adverse Health Effects Related to the Proposed Standards[a]

	2020	2030
Health Effect	Mean Incidence Reduction (5th – 95th %ile)	
PM-Related Endpoints		
Premature Mortality – Derived from Epidemiology Studies[b,c] Adult, age 30+ - Range based on Pope et al. 2002 and Laden et al.2006, Respectively	570 - 1,300 (220-920)–(710-1,900)	1,500 - 3,400 (590-2,400)-(1,900-5,000)
Infant, age <1 year – Woodruff et al. 1997	1 (1-2)	2 (1-4)
Premature Mortality – Derived from Expert Elicitation[c,d] Adult, age 25+ - Lower and Upper Bound EE Results, Respectively	180 - 1,700 (0-830) – (870-2,600)	460 - 4,600 (0-2,200) – (2,300-6,900)
Chronic bronchitis (adult, age 26 and over)	370 (68 – 670)	940 (170 – 1,700)
Acute myocardial infarction (adults, age 18 and older)	1,200 (640 – 1,700)	3,300 (1,800 – 4,800)
Hospital admissions—respiratory (all ages)[e]	130 (65 – 200)	350 (170 – 510)
Hospital admissions—cardiovascular (adults, age >18)[f]	270 (170 – 380)	770 (490 – 1,100)
Emergency room visits for asthma (age 18 years and younger)	460 (270 – 650)	1,000 (620 – 1,500)
Acute bronchitis (children, age 8–12)	1,000 (0 – 2,100)	2,600 (0 – 5,300)
Lower respiratory symptoms (children, age 7–14)	11,000 (5,400 – 17,000)	28,000 (14,000 – 43,000)
Upper respiratory symptoms (asthmatic children, age 9–18)	8,300 (2,600 – 14,000)	21,000 (6,600 – 35,000)
Asthma exacerbation (asthmatic children, age 6–18)	10,000 (1,100 – 29,000)	26,000 (2,800 – 74,000)
Work loss days (adults, age 18–65)	71,000 (62,000 – 81,000)	170,000 (150,000 – 190,000)
Minor restricted-activity days (adults, age 18–65)	420,000 (360,000 – 490,000)	1,000,000 (850,000 – 1,200,000)

[a] Incidence is rounded to two significant digits. PM estimates represent benefits from the proposed standards nationwide.

[b] Based on application of the effect estimate derived from the Pope et al (2002) cohort study and the Laden et al (2006) study.[48,49] Note that these two estimates are not additive; instead, they provide a range of mortality incidence derived from the epidemiology literature. Infant premature mortality based upon studies by Woodruff, et al. 1997.[50]

[c] PM-related mortality benefits estimated using an assumed PM threshold at 10 µg/m3. There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate.

[d] Based on effect estimates derived from the full-scale expert elicitation assessing the uncertainty in the concentration-response function for PM-related premature mortality (IEc, 2006).[51] The lower bound result reflects the function derived from the expert with the most conservative effect estimate. The upper bound result reflects the

function derived from the expert with the least conservative effect estimate. It should be noted, however, that the weight of expert-based opinion on the risk of premature death is skewed towards the range reflected by the published scientific studies. The effect estimates of nine of the twelve experts included in the elicitation panel falls within the scientific study-based range provided by Pope and Laden. One of the experts fall below this range and two of the experts are above this range.

[e] Respiratory hospital admissions for PM include admissions for COPD, pneumonia, and asthma.

[f] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 6.4-2. Estimated Monetary Value in Reductions in Incidence of Health and Welfare Effects (in millions of 2005$)[a,b]

	2020	2030
$PM_{2.5}$-Related Health Effect	Estimated Mean Value of Reductions (5th and 95th %ile)	
Premature mortality – Derived from Epidemiology Studies[c,d,e]		
Adult, age 30+ - ACS study (Pope et al. 2002)		
3% discount rate	$3,900 ($500 - $8,800)	$10,000 ($1,500 - $24,000)
7% discount rate	$3,700 ($500 - $7,900)	$9,400 ($1,300 - $21,000)
Adult, age 30+ - Six-Cities study (Laden et al. 2006)		
3% discount rate	$8,700 ($1,400 - $18,000)	$24,000 ($3,800 - $50,000)
7% discount rate	$7,800 ($1,300 - $17,000)	$21,000 ($3,400 - $45,000)
Infant Mortality,<1 year – Woodruff et al. 1997		
3% discount rate	$8 ($1 - $18)	$17 ($3 - $37)
7% discount rate	$7 ($1 - $16)	$15 ($2 - $$33)
Premature mortality – Derived from Expert Elicitation[c,d,e,f]		
Adult, age 25+ - Lower bound EE result		
3% discount rate	$1,200 ($0 - $7,200)	$3,300 ($0 - $20,000)
7% discount rate	$1,100 ($0 - $6,500)	$3,000 ($0 - $18,000)
Adult, age 25+ - Upper bound EE result		
3% discount rate	$12,000 ($1,800 - $25,000)	$31,000 ($4,800 - $68,000)
7% discount rate	$11,000 ($1,600 - $23,000)	$28,000 ($4,400 - $62,000)
Chronic bronchitis (adults, 26 and over)	$200 ($10 - $800)	$500 ($26 - $2,100)
Non-fatal acute myocardial infarctions		
3% discount rate	$123 ($32 - $270)	$330 ($80 - $730)
7% discount rate	$119 ($30 - $270)	$320 ($76 - $720)
Hospital admissions for respiratory causes	$2.7 ($1.3 - $4.0)	$7.2 ($3.6 - $11)
Hospital admissions for cardiovascular causes	$7.3 ($4.6 - $10)	$21 ($13 - $28)
Emergency room visits for asthma	$0.16	$0.37

	($0.09 - $0.26)	($0.20 - $0.60)
Acute bronchitis (children, age 8–12)	$0.44 ($0 - $1.2)	$1.1 ($0 - $3.1)
Lower respiratory symptoms (children, 7–14)	$0.21 ($0.07 - $0.43)	$0.53 ($0.18 - $1.1)
Upper respiratory symptoms (asthma, 9–11)	$0.24 ($0.05 - $0.59)	$0.62 ($0.14 - $1.5)
Asthma exacerbations	$0.53 ($0.04 - $2.0)	$1.4 ($0.10 - $5.1)
Work loss days	$11 ($9.6 - $12)	$27 ($23 - $30)
Minor restricted-activity days (MRADs)	$12 ($0.61 – $25)	$29 ($1.5 - $60)
Recreational Visibility, 86 Class I areas	$150 (na)[f]	$400 (na)
Monetized Total – PM-Mortality Derived from Epi. Studies; Morbidity Functions 3% discount rate 7% discount rate	$4.4 - $9.2 Billion ($1.0 - $10) – ($1.6 - $20) $4.0 - $8.3 Billion ($1.0 - $9.2) – ($1.5 - $18)	$12 - $25 Billion ($2.1 - $27) – ($4.4 - $53) $11 - $23 Billion ($1.8 - $25) – ($3.9 - $48)
Monetized Total – PM-Mortality Derived from Expert Elicitation[g]; Morbidity Functions 3% discount rate 7% discount rate	$1.7 - $12 Billion($0.2 - $8.5) – ($2.0 - $27)$1.6 - $11 Billion($0.2 - $7.8) – ($1.8 - $24)	$4.6 - $33 Billion($1.0 - $23) – ($5.4 - $72)$4.3 - $30 Billion($1.0 - $21) – ($4.9 - $65)

[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM benefits are nationwide.

[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2020 or 2030)

[c] PM-related mortality benefits estimated using an assumed PM threshold of 10 µg/m3. There is uncertainty about which threshold to use and this may impact the magnitude of the total benefits estimate.

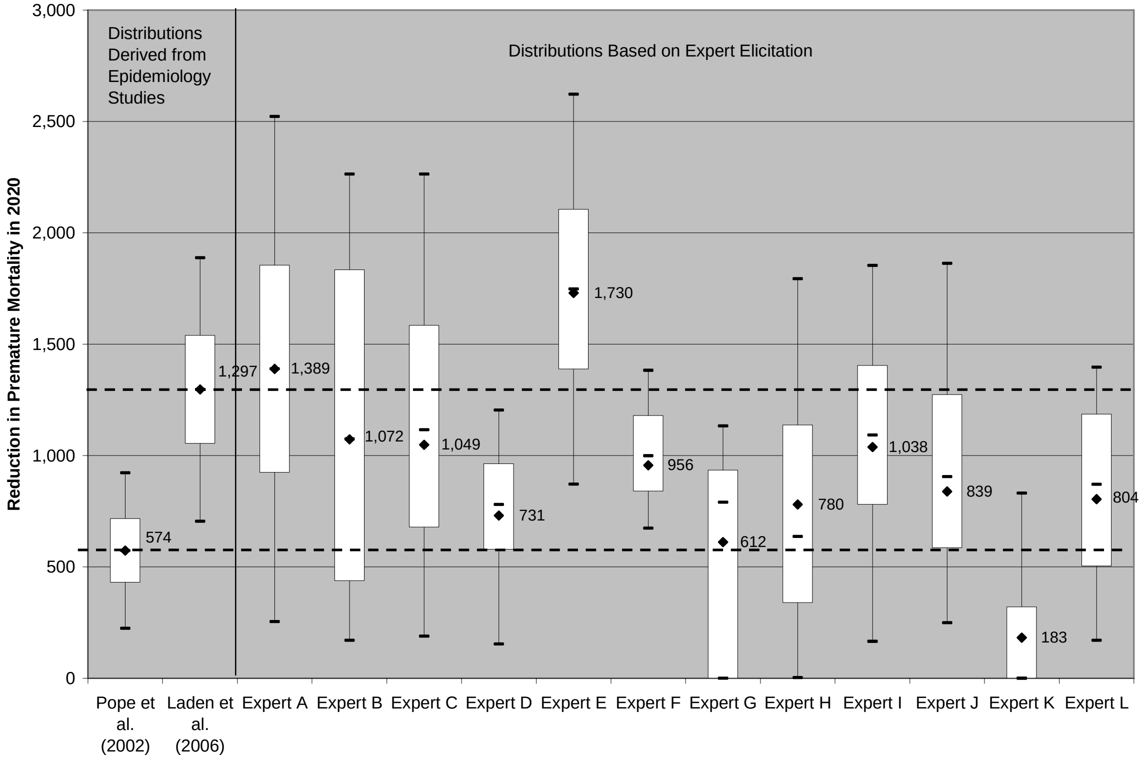
[d] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses (EPA, 2000; OMB, 2003).[i,ii]

[e] The valuation of adult premature mortality, derived either from the epidemiology literature or the expert elicitation, is not additive. Rather, the valuations represent a range of possible mortality benefits.

[f] We are unable at this time to characterize the uncertainty in the estimate of benefits of worker productivity and improvements in visibility at Class I areas. As such, we treat these benefits as fixed and add them to all percentiles of the health benefits distribution.

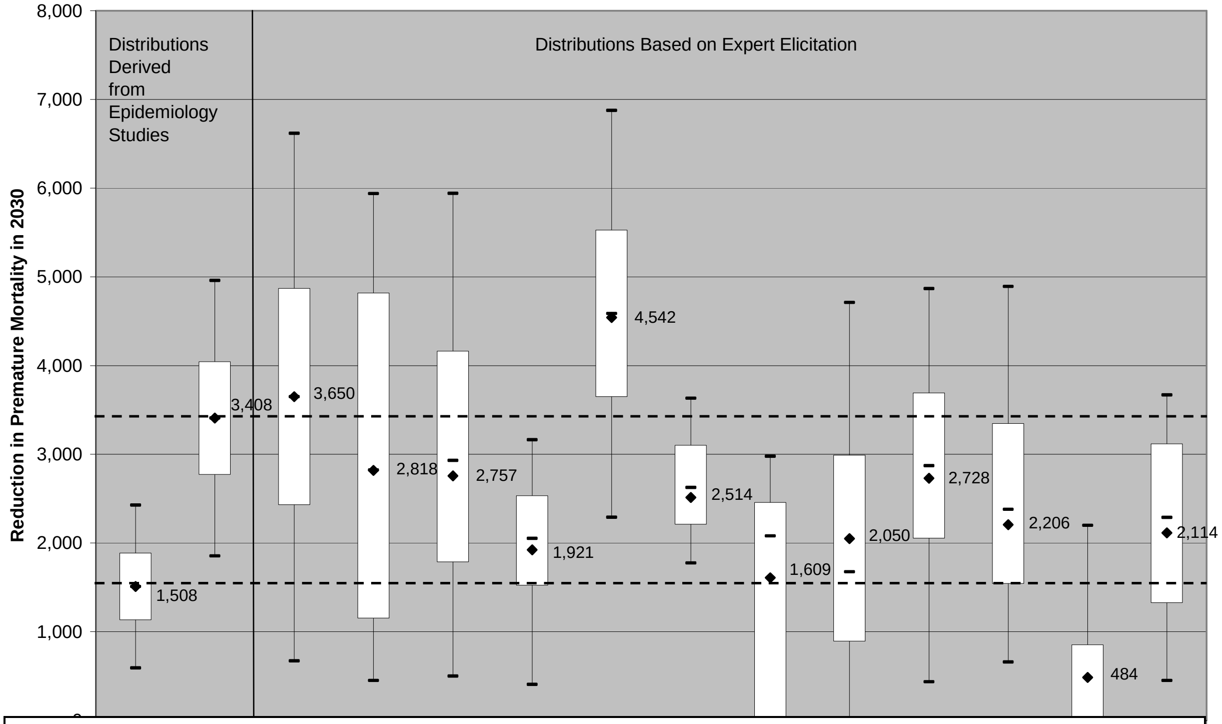
[g] It should be noted that the effect estimates of nine of the twelve experts included in the elicitation panel falls within the scientific study-based range provided by Pope and Laden. One of the experts fall below this range and two of the experts are above this range.

Figure 6.4-1. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with the Proposed Standards



Note: Distributions labeled Expert A – Expert L are based on individual expert responses. The distributions labeled Pope et al. (2002) and Laden et al. (2006) are based on the means and standard errors of the C-R functions from the studies. The dotted lines enclose a range bounded by the means of the two data-derived distributions.

Figure 6.4-2. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Proposed Standards



Note: Distributions labeled Expert A – Expert L are based on individual expert responses. The distributions labeled Pope et al. (2002) and Laden et al. (2006) are based on the means and standard errors of the C-R functions from the studies. The dotted lines enclose a range bounded by the means of the two data-derived distributions.

Table 6.4-3. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2020 Associated with the Proposed Standards

Source of Mortality Estimate	2020 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	220	570	920
Laden et al. (2006)	710	1,300	1,900
Expert A	250	1,400	2,500
Expert B	170	1,100	2,300
Expert C	190	1,000	2,300
Expert D	150	730	1,200
Expert E	870	1,700	2,600
Expert F	670	960	1,400
Expert G	0	610	1,100
Expert H	3	780	1,800
Expert I	170	1,000	1,900
Expert J	250	840	1,900
Expert K	0	180	830
Expert L	170	800	1,400

Table 6.4-4. Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Proposed Standards

Source of Mortality Estimate	2020 Primary Option		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	590	1,500	2,400
Laden et al. (2006)	1,900	3,400	5,000
Expert A	670	3,700	6,600
Expert B	450	2,800	5,900
Expert C	500	2,800	5,900
Expert D	400	1,900	3,200
Expert E	2,300	4,500	6,900
Expert F	1,800	2,500	3,600
Expert G	0	1,600	3,000
Expert H	8	2,100	4,700
Expert I	440	2,700	4,900
Expert J	660	2,200	4,900
Expert K	0	480	2,200
Expert L	450	2,100	3,700

Table 6.4-5. PM-Related Mortality Benefits of the Proposed Standards: Cutpoint Sensitivity Analysis Using the ACS Study (Pope et al., 2002)[a]

Certainty that Benefits are At Least Specified Value	Level of Assumed Threshold	Discount Rate	PM Mortality Benefits (Billion 2005$)	
			2020	2030
More Certain that Benefits Are at Least as Large ↓ Less Certain that Benefits Are at Least as Large	14 µg/m3 [b]	3%	$1.8	$5.4
		7%	$1.6	$4.8
	12 µg/m3	3%	$2.5	$7.2
		7%	$2.3	$6.5
	10 µg/m3 [c]	3%	$3.9	$10.4
		7%	$3.5	$9.4
	7.5 µg/m3 [d]	3%	$3.4	$9.2
		7%	$3.1	$8.3
	3 µg/m3 [e]	3%	$3.4	$9.2
		7%	$3.1	$8.3

[a] Note that this table only presents the effects of a cutpoint on PM-related mortality incidence and valuation estimates.

[b] Alternative annual PM NAAQS.

[c] CASAC (2005)[85]

[d] SAB-HES (2004)[86]

[e] NAS (2002)[87]

6.5 Comparison of Costs and Benefits

In estimating the net benefits of the proposed standards, the appropriate cost measure is 'social costs.' Social costs represent the welfare costs of a rule to society. These costs do not consider transfer payments (such as taxes) that are simply redistributions of wealth. Table 6.5-1 contains the estimates of monetized benefits and estimated social welfare costs for the proposed rule and each of the proposed control programs. The annual social welfare costs of all provisions of this proposed rule are described more fully in Chapter 7 of this RIA.[EE]

[EE] The estimated 2030 social welfare cost of 267.3 million is based on an earlier version of the engineering costs of the rule which estimated $568.3 million engineering costs in 2030 (see table 5-17). The current engineering cost estimate for 2030 is $605 million. See Section V.C.5 for an explanation of the difference. The estimated social costs of the program will be updated for the final rule.

The results in Table 6.5-1 suggest that the 2020 monetized benefits of the proposed standards are greater than the expected social welfare costs. Specifically, the annual benefits of the total program would be between $4.4 + B billion and $9.2 + B billion annually in 2020 using a three percent discount rate (or $4.0 and $8.3 billion assuming a 7 percent discount rate), compared to estimated social costs of approximately $250 million in that same year. These benefits are expected to increase to between $12 + B billion and $25 + B billion annually in 2030 using a three percent discount rate (or $11 and $23 billion assuming a 7 percent discount rate), while the social costs are estimated to be approximately $600 million. Though there are a number of health and environmental effects associated with the proposed standards that we are unable to quantify or monetize (represented by "+B"; see Table 6.1-2), the benefits of the proposed standards far outweigh the projected costs. When we examine the benefit-to-cost comparison for the rule standards separately, we also find that the benefits of the specific engine class standards far outweigh their projected costs.

Table 6.5-1. Summary of Annual Benefits and Costs of the Proposed Standards[a]
(Millions of 2005 dollars)

Description	2020 (Millions of 2005 dollars)	2030 (Millions of 2005 dollars)
Estimated Social Costs[b]		
Locomotive	$147	$383
Marine	$103	$222
Total Social Costs	$250	$605
Estimated Health Benefits of the Proposed Standards[c,d]		
Locomotive		
3 percent discount rate	$2,300+B - $4,800+B	$4,700+B - $9,800+B
7 percent discount rate	$2,100+B - $4,400+B	$4,300+B - $8,900+B
Marine		
3 percent discount rate	$2,100+B - $4,400+B	$7,100+B - $15,000+B
7 percent discount rate	$1,900+B - $3,900+B	$6,400+B - $14,000+B
Total Benefits		
3 percent discount rate	$4,400+B - $9,200+B	$12,000+B - $25,000+B
7 percent discount rate	$4,000+B - $8,300+B	$11,000+B - $23,000+B
Annual Net Benefits (Total Benefits – Total Costs)		
3 percent discount rate	$4,150+B - $8,950+B	$11,400+B - $24,400+B
7 percent discount rate	$3,750+B - $8,050+B	$10,400+B - $22,400+B

[a] All estimates are rounded to three significant digits and represent annualized benefits and costs anticipated for the years 2020 and 2030. Totals may not sum due to rounding.

[b] The calculation of annual costs does not require amortization of costs over time. Therefore, the estimates of annual cost do not include a discount rate or rate of return assumption (see Chapter 7 of the RIA).In Chapter 7, however, we

do use both a 3 percent and 7 percent social discount rate to calculate the net present value of total social costs consistent with EPA and OMB guidelines for preparing economic analyses.[FF]

[c] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses. Valuation of premature mortality based on long-term PM exposure assumes discounting over the SAB recommended 20-year segmented lag structure described in the Regulatory Impact Analysis for the Final Clean Air Interstate Rule (March, 2005). Note that the benefits in this table reflect PM mortality derived from the ACS (Pope et al., 2002) and Six-Cities (Laden et al., 2006) studies. Valuation of nonfatal myocardial infarctions (MI) assumes discounting over a 5-year period, reflecting lost earnings and direct medical costs following a nonfatal MI. Note that we do not calculate a net present value of benefits associated with the proposed standards.

[d] Not all possible benefits or disbenefits are quantified and monetized in this analysis. B is the sum of all unquantified benefits and disbenefits. Potential benefit categories that have not been quantified and monetized are listed in Table 6.1-2.

[FF] U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. www.yosemite1.epa.gov/ee/epa/eed/hsf/pages/Guideline.html.
Office of Management and Budget, The Executive Office of the President, 2003. Circular A-4. http://www.whitehouse.gov/omb/circulars.

Appendix 6.A Health-Based Cost Effectiveness Analysis

Health-based cost-effectiveness analysis (CEA) and cost-utility analysis (CUA) have been used to analyze numerous health interventions but have not been widely adopted as tools to analyze environmental policies. The Office of Management and Budget (OMB) recently issued Circular A-4 guidance on regulatory analyses, requiring federal agencies to “prepare a CEA for all major rulemakings for which the primary benefits are improved public health and safety to the extent that a valid effectiveness measure can be developed to represent expected health and safety outcomes.” Environmental quality improvements may have multiple health and ecological benefits, making application of CEA more difficult and less straightforward. For the recently finalized PM NAAQS analysis, CEA provided a useful framework for evaluation: non-health benefits were substantial, but the majority of quantified benefits came from health effects. EPA included in the PM NAAQS RIA a preliminary and experimental application of one type of CEA—a modified quality-adjusted life-years (QALYs) approach. A detailed description of this QALY approach is provided in Appendix G of the final PM NAAQS RIA. For the analysis presented here, we use the same modified QALY approach to characterize the health-based cost effectiveness of the proposed standards.

QALYs were developed to evaluate the effectiveness of individual medical treatments, and EPA is still evaluating the appropriate methods for CEA of environmental regulations. Agency concerns with the standard QALY methodology include the treatment of people with fewer years to live (the elderly); fairness to people with preexisting conditions that may lead to reduced life expectancy and reduced quality of life; and how the analysis should best account for nonhealth benefits, such as improved visibility.

The Institute of Medicine (a member institution of the National Academies of Science) established the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation to assess the scientific validity, ethical implications, and practical utility of a wide range of effectiveness measures used or proposed in CEA. This committee prepared a report titled “Valuing Health for Regulatory Cost-Effectiveness Analysis,” which concluded that CEA is a useful tool for assessing regulatory interventions to promote human health and safety, although not sufficient for informed regulatory decisions (Miller, Robinson, and Lawrence, 2006).[54] They emphasized the need for additional data and methodological improvements for CEA analyses, and urged greater consistency in the reporting of assumptions, data elements, and analytic methods. They also provided a number of recommendations for the conduct of regulatory CEA analyses. EPA is evaluating these recommendations and will determine a response for upcoming analyses.

The methodology derived from the final PM NAAQS analysis is not intended to stand as precedent either for future air pollution regulations or for other EPA regulations where it may be inappropriate. It is intended solely to demonstrate one particular approach to estimating the cost-effectiveness of reductions in ambient $PM_{2.5}$ in achieving improvements in public health. Reductions in ambient $PM_{2.5}$ likely will have other health and environmental benefits that will not be reflected in this CEA. Other EPA regulations affecting other aspects of environmental quality and public health may require additional data and models that may preclude the development of similar health-based CEAs. A number of additional methodological issues must be considered when conducting CEAs for environmental policies, including treatment of nonhealth effects, aggregation of acute and long-term health impacts, and aggregation of life extensions and quality-of-life improvements in different populations. The appropriateness of health-based CEA should be evaluated on a case-by-case basis subject to the availability of appropriate data and models, among other factors.

The proposed standards are expected to result in substantial reductions in potential population exposure to ambient concentrations of PM by 2030. The benefit-cost analysis presented in this chapter shows that the proposed standards would achieve substantial health benefits whose monetized value far exceeds costs (net benefits are between $12 and $28 billion in 2030, based on empirically derived estimates of PM mortality and using a 3 percent discount rate). Despite the risk of oversimplifying benefits, cautiously-interpreted cost-effectiveness calculations may provide further evidence of whether the costs associated with the proposed standards are a reasonable health investment for the nation.

This analysis provides estimates of commonly used health-based effectiveness measures, including lives saved, life years saved (from reductions in mortality risk), and QALYs saved (from reductions in morbidity risk) associated with the reduction of ambient $PM_{2.5}$ due to the proposed standards. In addition, we use an alternative aggregate effectiveness metric, Morbidity Inclusive Life Years (MILY) to address some of the concerns about aggregation of life extension and quality-of-life impacts. It represents the sum of life years gained due to reductions in premature mortality and the QALY gained due to reductions in chronic morbidity. This measure may be preferred to existing QALY aggregation approaches because it does not devalue life extensions in individuals with preexisting illnesses that reduce quality of life. However, the MILY measure is still based on life years and thus still inherently gives more weight to interventions that reduce mortality and morbidity impacts for younger populations with higher remaining life expectancy. This analysis focuses on life extensions and improvements in quality of life through reductions in two diseases with chronic impacts: chronic bronchitis (CB) and nonfatal acute myocardial infarctions. Monte Carlo simulations are used to propagate uncertainty in several analytical parameters and characterize the distribution of estimated impacts. While the benefit-cost analysis presented in the RIA characterizes mortality impacts using a number of different sources for the PM mortality effect estimate, for this analysis, we focus on the mortality results generated using the effect estimate derived from the Pope et al. (2002) study.

Presented in three different metrics, the analysis suggests the following:

- In 2020, the proposed standards will result in:
    - 570 (95% CI: 180 – 960) premature PM-related deaths avoided, or
    - 5,900 (95% CI: 4,100 – 7,600) PM-related life years gained (discounted at 3 percent), or
    - 11,000 (95% CI: 7,900 – 18,000) MILYs gained (discounted at 3 percent).
- In 2030, the proposed standards will result in:
    - 1,500 (95% CI: 590 – 2,400) premature PM-related deaths avoided, or
    - 15,000 (95% CI: 10,000 – 20,000) PM-related life years gained (discounted at 3 percent), or
    - 23,000 (95% CI: 16,000 – 34,000) MILYs gained (discounted at 3 percent).
- Using a 7 percent discount rate, mean discounted life years gained are 3,700 for the proposed standards in 2020 and 9,500 in 2030; mean MILYs gained are 7,300 in 2020 and 15,000 in 2030. (The estimates of premature deaths avoided are not affected by the discount rate.)
- The associated reductions in CB and nonfatal acute myocardial infarctions will reduce medical costs by approximately $180 million in 2020 and $550 million in 2030 based on a 3 percent discount rate, or $120 million in 2020 and $440 million in 2030 based on a 7 percent discount rate.
- Other health and visibility benefits are valued at $200 million in 2020 and $510 million in 2030.

Direct private compliance costs for the proposed standards are $240 million in 2020 and $600 in 2030 (see Chapter 7 of this RIA for more discussion of the cost estimates). Therefore, the net costs (private compliance costs minus avoided cost of illness minus other benefits) are negative, indicating that the proposed standards result in cost savings. As such, traditional cost-effectiveness ratios are not informative. However, it is possible to calculate the maximum costs for the rule that would still result in cost-effective improvements in public health compared with standard benchmarks of $50,000 and $100,000 per MILY:

- Taking into account avoided medical costs and other benefits, annual costs of the proposed standards would need to exceed $920 million (95% CI: $700 million – $1,400 million) in 2020 and $2.2 billion (95% CI: $1.6 billion – $3.0 billion) in 2030 to have a cost per MILY that exceeds a benchmark of $50,000, based on a 3 percent discount rate.

- Annual costs of the proposed standards would need to exceed $1.5 billion (95% CI: $1.1 billion – $2.3 billion) in 2020 and $3.4 billion (95% CI: $2.4 billion – $4.7 billion) in 2030 to have a cost per MILY that exceeds a benchmark of $100,000, based on a 3 percent discount rate.

- Using a 7 percent discount rate, annual costs of the proposed standards would need to exceed $680 million in 2020 and $1.7 billion in 2030 to have a cost per MILY that exceeds a benchmark of $50,000, and would need to exceed $1.0 billion in 2020 and $2.5 billion in 2030 to have a cost per MILY that exceeds a benchmark of $100,000.

Given costs of $240 million and $600 million in 2020 and 2030, respectively, the proposed standards are clearly a very cost-effective way to achieve improvements in public health.

Tables 6.A-1 through 6.A-9 present the intermediate and summary results of the health-based CEA of the proposed standards. Note that the methods used to generate these estimates follow the same methods as those explained in Appendix G of the final PM NAAQS RIA. We refer the reader to that document for more details about this modified QALY approach to health-based CEA.

Table 6.A-1: Estimated Reduction in Incidence of All-cause Premature Mortality Associated with the Proposed Standards in 2020 and 2030

	Reduction in All-Cause Premature Mortality (95% CI)	
Age Interval	2020	2030
30 – 34	5 (2-9)	11 (3-18)
35 – 44	15 (5-26)	35 (11-59)
45 – 54	31 (10-52)	64 (20-110)
55 – 64	78 (25-130)	150 (49-260)
65 – 74	130 (40-210)	340 (110-570)
75 – 84	140 (46-240)	460 (150-780)
85+	180 (56-300)	450 (140-750)
Total	570 (180-960)	1,510 (480-2,500)

Table 6.A-2: Estimated Life Years Gained from All-cause Premature Mortality Risk Reductions Associated with the Proposed Standards in 2020 and 2030

	Life Years Gained from Mortality Risk Reduction, 3% Discount Rate (95% CI)	
Age Interval	2020	2030
25 – 34	120 (27-210)	250 (77-450)
35 – 44	350 (120-560)	800 (250-1,300)
45 – 54	610 (190-1,000)	1,300 (420-2,100)
55 – 64	1,300 (420-2,200)	2,500 (800-4,200)
65 – 74	1,600 (500-2,700)	4,300 (1,300-7,200)
75 – 84	1,300 (400-2,100)	4,100 (1,400-6,800)
85+	630 (200-1,100)	1,600 (520-2,700)
Total	5,900 (4,100-7,600)	15,000 (10,000-20,000)

Table 6.A-3: Estimated Reduction in Incidence of Chronic Bronchitis Associated with the Proposed Standards in 2020 and 2030

	Reduction in Incidence (95% Confidence Interval)	
Age Interval	2020	2030
25 – 34	88 (8-170)	200 (18-380)
35 – 44	99 (9-190)	250 (22-480)
45 – 54	91 (8-170)	210 (19-400)
55 – 64	93 (8-180)	200 (18-380)
65 – 74	66 (6-130)	190 (17-360)
75 – 84	32 (3-61)	110 (10-210)
85+	13 (1-26)	37 (3-70)
Total	480 (43-920)	1,200 (110-2,300)

Table 6.A-4: QALYs Gained per Avoided Incidence of CB

Age Interval		QALYs Gained per Incidence	
Start Age	End Age	Undiscounted	Discounted (3%)
25	34	12.21	6.56
35	44	9.84	5.90
45	54	7.54	5.06
55	64	5.36	4.03
65	74	3.41	2.85
75	84	2.15	1.93
85+		0.79	0.76

Table 6.A-5: Estimated Reduction in Nonfatal Acute Myocardial Infarctions Associated with the Proposed Standards in 2020 and 2030

	Reduction in Incidence (95% Confidence Interval)	
Age Interval	2020	2030
18 – 24	1 (0-1)	1 (1-2)
25 – 34	4 (2-5)	8 (4-11)
35 – 44	38 (20-55)	97 (52-140)
45 – 54	121 (65-177)	280 (150-410)
55 – 64	290 (160-420)	630 (340-920)
65 – 74	340 (190-500)	1,000 (550-1,500)
75 – 84	250 (140-370)	870 (470-1,300)
85+	130 (70-190)	360 (190-520)
Total	1,200 (640-1,700)	3,270 (1,800-4,800)

Table 6.A-6: QALYs Gained per Avoided Nonfatal Myocardial Infarction

Age Interval		QALYs Gained per Incidence	
Start Age	End Age	Undiscounted	Discounted (3%)
18	24	4.04	2.10
25	34	3.38	1.95
35	44	2.73	1.74
45	54	2.08	1.48
55	64	1.44	1.12
65	74	0.95	0.81
75	84	0.57	0.52
85+		0.31	0.30

Table 6.A-7. Estimated Gains in 3 Percent Discounted MILYs Associated with the Proposed Standards in 2020[a]

Age	Life Years Gained from Mortality Risk Reductions (95% CI)	QALY Gained from Reductions in Chronic Bronchitis (95% CI)	QALY Gained from Reductions in Acute Myocardial Infarctions (95% CI)	Total Gain in MILYs (95% CI)
18–24	-	-	3 (0-5)	3 (0-5)
25–34	120 (27-210)	560 (38-1,400)	15 (4-32)	710 (160-1,500)
35–44	350 (120-560)	590 (42-1,400)	170 (73-600)	1,100 (550-2,100)
45–54	610 (190-1,000)	460 (34-1,100)	420 (200-1,600)	1,500 (960-2,900)
55–64	1,300 (420-2,200)	380 (31-890)	710 (340-2,900)	2,400 (1,600-4,900)
65–74	1,600 (500-2.700)	190 (12-440)	820 (300-2,600)	2,600 (1,500-4,700)
75–84	1,300 (400-2,100)	62 (4-150)	460 (130-1,000)	1,800 (870-2,800)
85+	630 (200-1,100)	10 (1-23)	110 (43-300)	750 (340-1,300)
Total	5,900 (4,100-7,600)	2,300 (173-5,300)	2,700 (1,100-9,100)	11,000 (7,900-18,000)

[a] Note that all estimates have been rounded to two significant digits.

Table 6.A-8: Estimated Gains in 3 Percent Discounted MILYs Associated with the Proposed Standards in 2030[a]

Age	Life Years Gained from Mortality Risk Reductions (95% CI)	QALY Gained from Reductions in Chronic Bronchitis (95% CI)	QALY Gained from Reductions in Acute Myocardial Infarctions (95% CI)	Total Gain in MILYs (95% CI)
18–24	-	-	3 (0-5)	3 (0-5)
25–34	250 (77-450)	1,300 (79-3,100)	15 (4-32)	1,600 (340-3,400)
35–44	800 (250-1,300)	1,500 (85-3,500)	170 (76-590)	2,400 (1,000-4,600)
45–54	1,300 (420-2,100)	1,100 (75-2,500)	420 (200-1,600)	2,700 (1,600-4,900)
55–64	2,500 (800-4,200)	790 (61-1,800)	710 (360-2,900)	4,000 (2,500-7,100)
65–74	4,300 (1,300-7,200)	530 (38-1,200)	820 (310-2,500)	5,600 (2,900-9,400)
75–84	4,100 (1,400-6,800)	210 (14-500)	460 (140-1,000)	4,800 (2,100-7,600)
85+	1,600 (520-2,700)	28 (2-66)	110 (44-300)	1,700 (700-2,900)
Total	15,000 (10,000-20,000)	5,400 (390-13,000)	2,700 (1,100-9,000)	23,000 (16,000-34,000)

[a] Note that all estimates have been rounded to two significant digits.

Table 6.A-9: Summary of Health-Based Cost Effectiveness Results for the Proposed Standards in 2020 and 2030[a]

	Result Using 3% Discount Rate (95% Confidence Interval)	
	2020	2030
Life years gained from mortality risk reductions	5,900 (4,100-7,600)	15,000 (10,000-20,000)
QALY gained from reductions in chronic bronchitis	2,300 (173-5,300)	5,400 (390-13,000)
QALY gained from reductions in acute myocardial infarctions	2,700 (1,100-9,100)	2,700 (1,100-9,000)
Total gain in MILYs	11,000 (7,900-18,000)	23,000 (16,000-34,000)
Avoided cost of illness		
Chronic bronchitis	$57 Million ($37 - $89 Million)	$130 Million ($86 - $210 Million)
Nonfatal AMI	$120 Million ($67 - $200 Million)	$420 Million ($170 - $550 Million)
Other benefits (based on COI and WTP estimates)	$200 Million ($180 - $210 Million)	$510 Million ($480 – $540 Million)
Implementation strategy costs[b]	$240 Million	$600 Million
Net cost per MILY	Cost Savings	Cost Savings

[a] All summary results are reported at a precision level of two significant digits to reflect limits in the precision of the underlying elements.

[b] Costs are the private firm costs of control, as discussed in Chapter 7, and reflect discounting using firm specific costs of capital.

Appendix 6.B Sensitivity Analyses of Key Parameters in the Benefits Analysis

The primary analysis presented in Chapter 6 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 the assumptions that are most appropriate to adopt in the face of important uncertainties and resource limitations. The majority of the analytical assumptions used to develop the primary estimates of benefits have been used to support similar rulemakings and approved by EPA's Science Advisory Board (SAB). Both EPA and the SAB recognize that data and modeling limitations as well as simplifying assumptions can introduce significant uncertainty into the benefit results and that alternative choices exist for some inputs to the analysis, such as the mortality C-R functions.

This appendix supplements our primary estimates of benefits with a series of sensitivity calculations that use other sources of health effect estimates and valuation data for key benefits categories. The supplemental estimates examine sensitivity to both valuation issues and for physical effects issues. These supplemental 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. The individual adjustments in the tables should not simply be added together because: 1) there may be overlap among the alternative assumptions; and 2) the joint probability among certain sets of alternative assumptions may be low.

6.B.1 Premature Mortality - Alternative Lag Structures

Over the last ten years, there has been a continuing discussion and evolving advice regarding the timing of changes in health effects following changes in ambient air pollution. It has been hypothesized that some reductions in premature mortality from exposure to ambient $PM_{2.5}$ 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.

The SAB-HES has recognized this lack of direct evidence. However, in early advice, 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 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," (EPA-SAB-COUNCIL-ADV-00-001, 1999, p. 9).[55] In recent advice, the SAB-HES suggests that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause estimate (EPA-SAB-COUNCIL-ADV-04-002, 2004). They suggest that diseases with longer progressions should be characterized by longer-term lag structures, while air pollution impacts occurring in populations with existing disease may be characterized by shorter-term lags.

A key question is the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies. Although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of the disease, it is not at all clear what the appropriate lag structure should be for cardiopulmonary deaths, which include both respiratory and cardiovascular causes. Some respiratory diseases may have a long period of progression, while others, such as pneumonia, have a very short duration. In the case of cardiovascular disease, there is an important question of whether air pollution is causing the disease, which would imply a relatively long cessation lag, or whether air pollution is causing premature death in individuals with preexisting heart disease, which would imply very short cessation lags.

The SAB-HES provides several recommendations for future research that could support the development of defensible lag structures, including using disease-specific lag models and constructing a segmented lag distribution to combine differential lags across causes of death (EPA-SAB-COUNCIL-ADV-04-002, 2004). The SAB-HES indicated support for using “a Weibull distribution or a simpler distributional form made up of several segments to cover the response mechanisms outlined above, given our lack of knowledge on the specific form of the distributions,” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24). However, they noted that “an important question to be resolved is what the relative magnitudes of these segments should be, and how many of the acute effects are assumed to be included in the cohort effect estimate,” (EPA-SAB-COUNCIL-ADV-04-002, 2004, p. 24-25). Since the publication of that report in March 2004, EPA has sought additional clarification from this committee. In its follow-up advice provided in December 2004, the SAB suggested that until additional research has been completed, EPA should assume a segmented lag structure characterized by 30 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 20 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$ (EPA-COUNCIL-LTR-05-001, 2004).[56] The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. Furthermore, in their advisory letter, the SAB-HES recommended that EPA include sensitivity analyses on other possible lag structures. In this appendix, we investigate the sensitivity of premature mortality-reduction related benefits to alternative cessation lag structures, noting that ongoing and future research may result in changes to the lag structure used for the primary analysis.

In previous advice from the SAB-HES, they recommended an analysis of 0-, 8-, and 15-year lags, as well as variations on the proportions of mortality allocated to each segment in the segmented lag structure (EPA-SAB-COUNCIL-ADV-00-001, 1999, (EPA-COUNCIL-LTR-05-001, 2004). 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)[57] and Dockery et al. (1993)[58] studies, respectively.[GG] However, neither the Pope et al. nor 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. analyses do not support or refute 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).

In addition to the simple 8- and 15-year lags, we have added two additional sensitivity analyses examining the impact of assuming different allocations of mortality to the segmented lag of the type suggested by the SAB-HES. The first sensitivity analysis assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes. This illustrative lag structure is characterized by 20 percent of mortality reductions occurring in the first year, 50 percent occurring evenly over years 2 to 5 after the reduction in $PM_{2.5}$, and 30 percent occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$. The second sensitivity analysis assumes the 5-year distributed lag structure used in previous analyses, which is equivalent to a three-segment lag structure with 50 percent in the first 2-year segment, 50 percent in the second 3-year segment, and 0 percent in the 6- to 20-year segment.

The estimated impacts (scaled from the CAND analysis) of alternative lag structures on the monetary benefits associated with reductions in PM-related premature mortality (estimated with the Pope et al. ACS impact function) are presented in Table 6B-1. These estimates are based on the value of statistical lives saved approach (i.e., $5.5 million per incidence) and are presented using both a 3 percent and 7 percent discount rate over the lag period.

[GG] 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.

Table 6B-1. Sensitivity of Benefits of Premature Mortality Reductions to Alternative Lag Assumptions (Relative to Primary Benefits Estimates of the Proposed Standards)

Description of Sensitivity Analysis		Avoided Incidences[a] 2020	Avoided Incidences[a] 2030	Value (million 2005$)[b] 2020	Value (million 2005$)[b] 2030
Alternative Lag Structures for PM-Related Premature Mortality					
None	Incidences all occur in the first year	570	1,500	$4,300	$11,500
8-year	Incidences all occur in the 8th year				
	3% Discount Rate	570	1,500	$3,500	$9,300
	7% Discount Rate	570	1,500	$2,600	$7,100
15-year	Incidences all occur in the 15th year				
	3% Discount Rate	570	1,500	$2,800	$7,600
	7% Discount Rate	570	1,500	$1,600	$4,400
Alternative Segmented	20 percent of incidences occur in 1st year, 50 percent in years 2 to 5, and 30 percent in years 6 to 20				
	3% Discount Rate	570	1,500	$3,700	$10,100
	7% Discount Rate	570	1,500	$3,200	$8,700
5-Year Distributed	50 percent of incidences occur in years 1 and 2 and 50 percent in years 2 to 5				
	3% Discount Rate	570	1,500	$4,000	$10,900
	7% Discount Rate	570	1,500	$3,800	$10,200

[a] Incidences rounded to two significant digits.

[b] Dollar values rounded to two significant digits. Note that dollar values reflect the use of a 3 percent discount rate in the primary lag adjustment for valuation of alternative mortality C-R functions. The alternative lag structure analysis presents benefits calculated using both a 3 percent and 7 percent discount rate.

The results of the scaled alternative lag sensitivity analysis demonstrate that choice of lag structure can have a large impact on benefits. Because of discounting of delayed benefits, the lag structure may have a large downward impact on monetized benefits if an extreme assumption that no effects occur until after 15 years is applied. However, for most reasonable distributed lag structures, differences in the specific shape of the lag function have relatively small impacts on overall benefits. For example, the overall impact of moving from the previous 5-year distributed lag to the segmented lag recommended by the SAB-HES in 2004 in the 2030 primary estimate is relatively modest, reducing PM-related mortality benefits by approximately 5 percent when a 3 percent discount rate is used and approximately 10 percent when a 7 percent discount rate is used. If no lag is assumed, benefits increase by around 10 percent relative to the segmented lag with a 3 percent discount rate and 23 percent with a 7 percent discount rate.

6.B.2 Visibility Benefits in Additional Class I Areas

The Chestnut and Rowe (1990) study from which the primary visibility valuation estimates are derived only examined WTP for visibility changes in Class I areas (national parks and wilderness areas) in the southeast, southwest, and California. To obtain estimates of WTP for visibility changes at national parks and wilderness areas in the northeast, northwest, and central regions of the U.S., we have to transfer WTP values from the studied regions. 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.

Based on this benefits transfer methodology (implemented within the preference calibration framework discussed in Chapter 5 and Appendix I of the final PM NAAQS RIA), estimated additional visibility benefits in the northwest, central, and northeastern U.S. are provided in Table 6B-2.

Table 6.B-2: Monetary Benefits Associated with Improvements in Visibility in Additional Federal Class I Areas in 2020 and 2030 (in millions of 2005$)[a]

Year	Northwest[b]	Central[c]	Northeast[d]	Total
2020	$11	$55	$10	$75
2030	$30	$130	$20	$180

[a] All estimates are rounded to 2 significant digits. All rounding occurs after final summing of unrounded estimates. As such, totals will not sum across columns

[b] Northwest Class I areas include Crater Lake, Mount Rainier, North Cascades, and Olympic national parks, and Alpine Lakes, Diamond Peak, Eagle Cap, Gearhart Mountain, Glacier Peak, Goat Rocks, Hells Canyon, Kalmiopsis, Mount Adams, Mount Hood, Mount Jefferson, Mount Washington, Mountain Lakes, Pasayten, Strawberry Mountain, and Three Sisters wilderness areas.

[c] Central Class I areas include Craters of the Moon, Glacier, Grand Teton, Theodore Roosevelt, Badlands, Wind Cave, and Yellowstone national parks, and Anaconda-Pintlar, Bob Marshall, Bridger, Cabinet Mountains, Fitzpatrick, Gates of the Mountain, Lostwood, Medicine Lake, Mission Mountain, North Absaroka, Red Rock Lakes, Sawtooth, Scapegoat, Selway-Bitterroot, Teton, U.L. Bend, and Washakie wilderness areas.

[d] Northeast Class I areas include Acadia, Big Bend, Guadalupe Mountains, Isle Royale, Voyageurs, and Boundary Waters Canoe national parks, and Brigantine, Caney Creek, Great Gulf, Hercules-Glades, Lye Brook, Mingo, Moosehorn, Presidential Range-Dry Roosevelt Campobello, Seney, Upper Buffalo, and Wichita Mountains wilderness areas.

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CHAPTER 7: Economic Impact Analysis

We prepared an Economic Impact Analysis (EIA) to estimate the economic impacts of the proposed emission control program on the locomotive and marine diesel engine and vessel markets. In this chapter we describe the Economic Impact Model (EIM) we developed to estimate the market-level changes in prices and outputs for affected markets, the social costs of the program, and the expected distribution of those costs across stakeholders. We also present the result of our analysis.

We estimate the social costs of the proposed program to be approximately $600 million in 2030.[1, 2] The impact of these costs on society are expected to be minimal, with the prices of rail and marine transportation services estimated to increase by less about 0.4 percent for locomotive transportation services and about 0.6 percent for marine transportation services. The rail sector is expected to bear about 64 percent of the social costs of the program in 2030, and the marine sector is expected to bear about 36 percent. In each of these two sectors, these social costs are expected to be born primarily by producers and users of locomotive and marine transportation services (63.3 and 33.2 percent, respectively). The remaining 3.5 percent is expected to be borne by locomotive, marine engine, and marine vessel manufacturers and fishing and recreational vessel users.

With regard to market-level impacts in 2030, the average price of a locomotive is expected to increase about 2.6 percent ($49,100 per unit), but sales are not expected to decrease. In the marine markets, the expected impacts are different for engines above and below 800 hp. With regard to engines above 800 hp and the vessels that use them, the average price of an engine is expected to increase by about 8.4 percent for C1 engines and 18.7 percent for C2 engines ($13,300 and $48,700, respectively). However, the expected impact of these increased prices on the average price of vessels that use these engines is smaller, at about 1.1 percent and 3.6 percent respectively ($16,200 and $141,600). The decrease in engine and vessel production is expected to be negligible, at less than 10 units. For engines less than 800 hp and the vessels that use them, the expected price increase and quantity decrease are expected to be negligible, less than 0.1 percent. Finally, even with the increases in the prices of locomotives and large marine diesel engines, the expected impacts on prices in the locomotive and marine transportation service markets are small, at 0.4 and 0.6 percent, respectively.

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[1] All estimates presented in this section are in 2005$.

[2] The estimated 2030 social welfare cost of 267.3 million is based on an earlier version of the engineering costs of the rule which estimated $568.3 million engineering costs in 2030 (see table 5-17). The current engineering cost estimate for 2030 is $605 million. See 7.1.4 for an explanation of the difference. The estimated social costs of the program will be updated for the final rule.

7.1 Overview and Results

7.1.1 What is an Economic Impact Analysis?

An EIA is prepared to inform decision makers about the potential economic consequences of a regulatory action. The analysis consists of estimating the social costs of a regulatory program and the distribution of these costs across stakeholders. These estimated social costs can then be compared with estimated social benefits (as presented in Chapter 6). As defined in EPA's *Guidelines for Preparing Economic Analyses*, social costs are the value of the goods and services lost by society resulting from a) the use of resources to comply with and implement a regulation and b) reductions in output.[1] In this analysis, social costs are explored in two steps. In the *market analysis*, we estimate how prices and quantities of goods and services affected by the proposed emission control program can be expected to change once the program goes into effect. In the *economic welfare analysis*, we look at the total social costs associated with the program and their distribution across key stakeholders.

7.1.2 What Methodology Did EPA Use in this Economic Impact Analysis?

The EIM is the behavioral model we developed to estimate price and quantity changes and total social costs associated with the emission controls under consideration. The model relies on basic microeconomic theory to simulate how producers and consumers of products and services affected by the emission requirements can be expected to respond to an increase in production costs as a result of the proposed emission control program. The economic theory that underlies the model is described in detail in Section 7.2.

The EIM is designed to estimate the economic impacts of the proposed program by simulating economic behavior. This is done by creating a model of the initial, pre-control market for a product, shocking it by the estimated compliance costs, and observing the impacts on the market. At the initial, pre-control market equilibrium, a market is characterized by a price and quantity combination at which producers are willing to produce the same amount of a product that consumers are willing to purchase at that price (supply is equal to demand). The control program under consideration would increase the production costs of affected goods by the amount of the compliance costs. This generates a "shock" to the initial equilibrium market conditions. Producers of affected products will try to pass some or all of the increased production costs on to the consumers of these goods through price increases. In response to the price increases, consumers will decrease their demand for the affected good. Producers will react to the decrease in quantity demanded by decreasing the quantity they produce; the market will react by setting a higher price for those fewer units. These interactions continue until a new market equilibrium price and quantity combination is achieved. The amount of the compliance costs that can be passed on to consumers is ultimately limited by the price sensitivity of purchasers and producers in the relevant market (represented by the price elasticity of demand and supply). The EIM explicitly models these behavioral responses and estimates new equilibrium prices and output and the resulting distribution of social costs across these stakeholders (producers and consumers).

The EIM is a behavioral model. The estimated social costs of this emission control program are a function of the ways in which producers and consumers of the engines and equipment affected by the standards change their behavior in response to the costs incurred in complying with the standards. These behavioral responses are incorporated in the EIM through the price elasticity of supply and demand (reflected in the slope of the supply and demand curves), which measure the price sensitivity of consumers and producers. An “inelastic” price elasticity (less than one) means that supply or demand is not very responsive to price changes (a one percent change in price leads to less than one percent change in demand). An “elastic” price elasticity (more than one) means that supply or demand is sensitive to price changes (a one percent change in price leads to more than one percent change in demand). A price elasticity of one is unit elastic, meaning there is a one-to-one correspondence between a change in price and change in demand. The price elasticities used in this analysis are described in Section 7.3 and are either from peer-reviewed literature or were estimated using well-established econometric methods. It should be noted that demand in the locomotive and marine engine and vessel markets is internally derived from the rail and marine transportation service markets as part of the process of running the model. This is an important feature of the EIM, which allows it to link the engine and equipment components of each model and simulate how compliance costs can be expected to ripple through the affected market.

7.1.3 What Economic Sectors are Included in the Economic Impact Model?

In this EIA we estimate the impacts of the proposed emission control program on two broad sectors: rail and marine. The characteristics of the markets analyzed that are relevant to the EIM are summarized in Table 7-1 and described in more detail in Section 7.3.

Table 7-1. Summary of Markets in Economic Impact Model

Model Dimension	Rail Sector	Marine Sector

Model Dimension	Rail Sector	Marine Sector
Description of Markets: Supply	Locomotive: locomotive manufacturers (integrated manufacturers); 3 categories Line Haul Passenger Switcher Rail Transportation Services: Entities that provide rail transportation services (railroads, primarily Class I)	Engines: Marine Engine Manufacturers; 8 categories Small: < 50 hp Category 1: 50-200 hp 200-400 hp 400-800 hp 800-2,000 hp > 2,000 hp Category 2: 800-2,000 hp > 2,000 hp Marine Vessels: Marine vessel manufacturers; 7 categories Tug/tow/pushboats Cargo vessels Ferry vessels Supply/crew boats Other commercial vessels Fishing boats Recreational boats Marine Transportation Services: Entities that provide marine transportation services (excludes fishing and recreational vessels)
Description of Markets: Demand	Locomotive: Railroads (primarily Class I) Rail transportation services: Entities that use rail transportation services (power, chemical, agricultural companies; personal transportation)	Marine Engines: Vessel manufacturers Marine Vessels: Marine vessel users (owners of all types of marine vessels) Marine transportation services: Entities that use marine transportation services (power, chemical, agricultural companies; personal transportation)
Geographic Scope	50 states	50 states
Market Structure	Perfectly competitive	Perfectly competitive
Baseline Population	Same as locomotive inventory analysis	PSR 2002 OE Link Sales Database
Growth Projections	Based on projected fuel consumption from Energy Information Agency	Commercial marine: 0.9% (0.009); recreational marine based on EPA's Nonroad Model

Model Dimension	Rail Sector	Marine Sector
Supply Elasticity	Locomotives (all): 2.7 (elastic) Rail Transportation Market: 0.6 (inelastic)	Engines: 3.8 (elastic) Vessels: 2.7 Commercial (elastic) 1.6 Recreational and Fishing (elastic) Marine Transportation Market: 0.6 (inelastic)
Demand Elasticity	Locomotives (all): Derived Rail Transportation Market: -0.5 (inelastic)	Engines: Derived Vessels: Commercial: Derived Recreational and Fishing : -1.4 (elastic) Marine Transportation Market: -0.5 (inelastic)
Regulatory Shock	Locomotive Market: direct engine and equipment compliance costs cause shift in supply function Rail Transportation Market: direct operating and remanufacturing compliance costs, in addition to higher locomotive prices, cause shift in supply function	Marine diesel engine: direct engine compliance costs cause shift in supply function Marine vessels: direct vessel compliance costs, in addition to higher engine prices, cause shift in supply function Marine Transportation Market: direct operating costs in addition to higher vessel prices cause shift in supply function

7.1.3.1 Rail Sector Component

The rail sector component of the EIM is a two-level model consisting of suppliers and users of locomotives and rail transportation services.

Locomotive Market. The locomotive market consists of locomotive manufacturers (line haul, switcher, and passenger) on the supply side and railroads on the demand side. The vast majority of locomotives built in any given year are for line haul applications; a small number of passenger locomotives are built every year, and even fewer switchers. The locomotive market is characterized by integrated manufacturers (the engine and locomotive are made by the same manufacturer) and therefore the engine and equipment impacts are modeled together. The EIM does not distinguish between power bands for locomotives. This is because while there is some variation in power for different engine models, the range is not large. On average line haul locomotives are typically about 4,000 hp, passenger locomotives are about 3,000 hp, and switchers are about 2,000 hp.

Recently, a new switcher market is emerging in which manufacturers are expected to be less integrated, and the manufacturer of the engine is expected to be separate from the manufacturer of the switcher.[3] Because the characteristics of this new market are speculative at this time, the switcher market component of the EIM is modeled in the same way as line haul locomotives (integrated manufacturers; same behavioral parameters), but uses separate baseline equilibrium prices and quantities. The compliance costs used for switchers reflect the expected design characteristics for these locomotives and their lower total power. Consistent with the cost analysis, the passenger market is combined with the switcher market in this EIA because we do not have separate compliance costs estimates for each of those two market segments.

Rail Transportation Services. The rail transportation services market consists of entities that provide and utilize rail transportation services. On this supply side, these are the railroads. On the demand side, these are rail transportation service users such as the chemical and agricultural industries and the personal transportation industry. Most of the goods moved by rail are bulk goods such as coal, chemicals, minerals, petroleum, and the like. About 26 percent of the carloads in 2004 were miscellaneous mixed shipments (mostly intermodal, e.g., containers) and about 6 percent were motor vehicles and equipment. This means that about 68 percent of the goods moved by rail are production inputs.[2] The EIM does not estimate the economic impact of the proposed emission control program on ultimate finished goods markets that use rail transportation services as inputs. This is because transportation services are only a small portion of the total variable costs of goods and services manufactured using these bulk inputs. Also, changes in prices of transportation services due to the estimated compliance costs are not expected to be large enough to affect the prices and output of goods that use rail transportation services as an input.

7.1.3.2 Marine Sector Component

The marine sector component of the EIM distinguishes between engine, vessel, and ultimate user markets (marine transportation service users, fishing users, recreational users). This is because, in contrast to the locomotive market, manufacturers in the diesel marine market are not integrated. Marine diesel engines and vessels are manufactured by different entities.

Marine Engine Market. The marine engine markets consist of marine engine manufacturers on the supply side and vessel manufacturers on the demand side. The model distinguishes between three types of engines, commercial propulsion, recreational

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[3] Until recently, switchers have typically been converted line haul locomotives and very few, if any, new dedicated switchers were built in any year. Recently, however, the power and other characteristics of line haul locomotives have made them less attractive for switcher usage. Their high power means they consume more fuel than smaller locomotives, and they have less attractive line-of-sight characteristics than what is needed for switchers. Therefore, the industry is anticipating a new market for dedicated switchers.

propulsion, and auxiliary. Engines are broken out into eight categories based on horsepower and displacement.

- Small marine diesel engines
    - <50 hp
- C1 engines
    - 50-200 hp
    - 200-400 hp
    - 400-800 hp
    - 800-2,000 hp
    - >2,000 hp
- C2 engines
    - 800-2,000 hp
    - >2,000 hp

For the purpose of the EIA, the C1/C2 threshold is 5 l/cyl displacement, even though the new C1/C2 threshold is proposed to be 7 l/cyl displacement. The 5 l/cyl threshold was used because it is currently applicable limit. In addition, there is currently only one engine family in the 5 to 7 l/cyl range, and it is not possible to project what future sales will be in that range or if more engine families will be added.

Marine Vessel Market. The marine vessel market consists of marine vessel manufacturers on the demand side and marine vessel users on the supply side. The model distinguishes between seven vessel categories. Each of these vessels would have at least one propulsion engine and at least one auxiliary engine:

- Recreational
- Fishing
- Tow/tug/push
- Ferry
- Supply/crew
- Cargo
- Other commercial

For fishing and recreational vessels, the purchasers of those vessels are the end users, and so the EIM is a two-level model for those two markets. For the fishing market, this approach is appropriate because demand for fishing vessels comes directly from the fishing industry; fishing vessels are a fixed capital input for that industry. For the recreational market, demand for vessels comes directly from households that use these vessels for recreational activities and acquire them for the personal enjoyment of the owner. For the other commercial vessel markets (tow/tug/push, ferry, supply/crew, cargo, other), demand is derived from the transportation services they provide, and so demand is from the transportation service market and the providers of those services more specifically. Therefore it is necessary to include the marine transportation services market in the model.

Marine Transportation Services. The marine transportation services market consists of entities that provide and utilize marine transportation services: vessel owners on the supply side and marine transportation service users on the demand side. The firms that use these marine transportation services are very similar to those that use locomotive transportation services: those needing to transport bulk chemicals and minerals, coal, agricultural products, etc. These transportation services are production inputs that depend on the amount of raw materials or finished products being transported and thus marine transportation costs are variable costs for the end user. Demand for these transportation services will determine the demand for vessels used to provide these services (tug/tow/pushboats, cargo, ferries, supply/crew, other commercial vessels).

7.1.3.3 Market Linkages

The individual levels of the rail and marine components of the EIM are linked to provide feedback between consumers and producers in the relevant markets. The locomotive and marine components of the EIM are not linked however, meaning there is no feedback mechanism between the locomotive and marine sectors. Although locomotives and marine vessels such as tugs, towboats, cargo, and ferries provide the same type of transportation service, the characteristics of these markets are quite different and are subject to different constraints that limit switching from one type of transportation service to the other. For example, switching from rail services to marine services requires having access to a port and the waterway system; if the production facility is not located on a waterway it would also be necessary to transport the goods to and from port. Similarly, users of marine transportation services typically transport bulk goods in large quantities (by barge or by container); these quantities may be more complicated and costly to transport by rail. Because the services provided by the locomotives and marine markets are not completely interchangeable, a change in the price of one is not expected to have an impact on the price for the other.

For the limited number of cases where there is direct competition between rail and marine transportation services, we do not expect this rule to change the dynamics of the choice between marine or rail providers of these services because 1) the estimated compliance costs imposed by this rule are relatively small in comparison with the total production costs of providing transportation services, and 2) both sectors would be subject to the new standards. So, for example, while an increase in the price of marine diesel engines may lead to an increase in the price of marine transportation services, this will not likely have much impact on the demand for rail services because the rail sector is also expected to see increased costs.

7.1.4 Summary of Results

The EIA consists of two parts: a market analysis and welfare analysis. The market analysis looks at expected changes in prices and quantities for affected products. The welfare analysis looks at economic impacts in terms of annual and present value changes in social costs.

We performed a market analysis for all years and all engines and equipment. The detailed results can be found in the appendices to this chapter. In this section we present summarized results for selected years.

Due to the structure of the program (see Section 7.3.3), the estimated market and social costs impacts of the program in the early years are small and are primarily due to the locomotive remanufacturing program. By 2016, the impacts of the program are more significant due to the operational costs associated with the Tier 4 standards (urea usage). Consequently, a large share of the social costs of the program after the Tier 4 standards to into effect fall on the marine and rail transportation service sectors. These operational costs are incurred by the providers of these services, but they are expected to pass along some of these costs to their customers.

The results of the economic impact analysis presented in this Chapter are based on an earlier version of the engineering costs developed for this rule. The engineering costs for 2030 presented in Chapter 5 are estimated to be $605 million, which is $37 million more than the compliance costs used in this EIA. Over the period from 2007 through 2040, the net present value of the engineering costs in Chapter 5 is $7.2 billion while the NPV of the estimated social costs over that period based on the compliance costs used in his chapter is $6.9 billion (3 percent discount rate). The differences are primarily in the form of operating costs ($22 million for the rail sector, $10 million for the marine sector). The variable costs for locomotives are slightly smaller ($4.0 million) and for marine are somewhat higher ($5.0 million). The difference for marine engines occurs in part because the engineering costs in Chapter 3 include Tier 4 costs for recreational marine engines over 2,000 kW. There are also small differences for the estimated operating costs. As a result of these differences, the amount of the social costs imposed on producers and consumers of rail and marine transportation services as a result of the proposed program would be larger than estimated in this section, while the impacts on the prices and quantities of locomotives would be slightly less. In addition, there would be larger social costs for the recreational marine sector. Nevertheless, the estimated market impacts and the distribution of the social costs among stakeholders would be about the same as those presented below.

7.1.4.1 Market Analysis Results

In the market analysis, we estimate how prices and quantities of goods affected by the proposed emission control program can be expected to change once the program goes into effect. The analysis relies on the baseline equilibrium prices and quantities for each type of equipment and the price elasticity of supply and demand. It predicts market reactions to the increase in production costs due to the new compliance costs (variable, operating, and remanufacturing costs). It should be noted that this analysis does not allow any other factors to vary. In other words, it does not consider that manufacturers may adjust their production processes or marketing strategies in response to the control program.

A summary of the market analysis results is presented in Table 7-2 for 2011, 2016, and 2030. These years were chosen because 2011 is the first year of the Tier 3 standards, 2016 is when the Tier 4 standards begin for most engines, and 2030 illustrates the long-term impacts of the program. Results for all years can be found in the appendices to this Chapter.

The estimated market impacts are designed to provide a broad overview of the expected market impacts that is useful when considering the impacts of the rule. Absolute price changes and relative price/quantity changes reflect production-weighted averages of the individual market-level estimates generated by the model for each group of engine/equipment markets. For example, the estimated marine diesel engine price changes are production-weighted averages of the estimated results for all of the marine diesel engine markets included in the group.[4] The absolute change in quantity is the sum of the decrease in units produced across sub-markets within each engine/equipment group. For example, the estimated marine diesel engine quantity changes reflect the total decline in marine diesel engines produced. The aggregated data presented in Table 7-2 is intended to provide a broad overview of the expected market impacts that is useful when considering the impacts of the rule on the economy as a whole and not the impacts on a particular engine or equipment category.

Locomotive Sector Impacts. On the locomotive side, the proposed program is expected to have a negligible impact on locomotive prices and quantities. In 2011, the expected impacts are mainly the result of the operating costs associated with locomotive remanufacturing standards. These standards impose an operating cost on railroad transportation providers and are expected to result in a slight increase in the price of locomotive transportation services (about 0.1 percent, on average) and a slight decrease in the quantity of services provided (about 0.1 percent, on average). The locomotive remanufacturing program is also expected to have a small impact on the new locomotive market. The remanufacturing program will increase railroad operating costs, which expected to result in an increase in the price of transportation services. This increase will results in a decrease in demand for rail transportation services and ultimately in a decrease in the demand for locomotives and a decrease in their price. In other words, the market will contract slightly. We estimate a reduction in the price of locomotives of about $425, or about 0.02 percent on average.

Beginning in 2016, the market impacts are affected by both the operating costs and the direct costs associated with the Tier 4 standards. As a result of both of these impacts, the price of a new locomotive is expected to increase by about 1.9 percent ($35,900), on average and the quantity produced is expected to decrease by about 0.1 percent, on average (less than 1 locomotive). Locomotive transportation service prices

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[4] As a result, estimates for specific types of engines and equipment may be different than the reported group average. The detail results for markets are reported in the Appendices to Chapter 7 of the RIA.

are expected to decrease by about 0.1 percent). By 2030, the price of new locomotives is expected to increase by about 2.6 percent ($49,000), on average, and the quantity expected to decrease by about 0.2 percent (less than 1 locomotive). The price of rail transportation services is expected to increase by about 0.4 percent.

Marine Sector Impacts. On the marine engine side, the expected impacts are different for engines above and below 800 hp. With regard to engines above 800 hp and the vessels that use them, the proposed program does not begin to affect market prices or quantities until the Tier 4 standards go into effect, which is in 2016 for most engines. For these engines, the price of a new engines in 2016 is expected to increase between 11.0 and 24.6 percent, on average ($17,300 for C1 engines above 800 hp and $64,100 for C2 engines above 800 hp), depending on the type of engine, and sales are expected to decrease less than 2.0 percent, on average. The price of vessels that use them is expected to increase between 1.7 and 1.0 percent ($20,900 for vessels that use C1 engines above 800 hp and $188,600 for vessels that use C2 engines above 800 hp) and sales are expected to decrease less than 2.0 percent. The percent change in price in the marine transportation sector is expected to be about 0.1 percent. By 2030, the price of these engines is expected to increase between 8.4 and 18.7 percent, on average ($13,300 for C1 engines above 800 hp and $48,700 for C2 engine above 800 hp), depending on the type of engine, and sales are expected to decrease by less than 2 percent, on average. The price of vessels that use them is expected to increase between 1 and 3.6 percent ($16,200 for vessels that use C1 engines above 800 hp and $141,600 for vessels that use C2 engines above 800 hp) and sales are expected to decrease by less than 2 percent. The percent change in price in the marine transportation is expected to be about 0.6 percent.

With regard to engines below 800 hp, the market impacts of the program are expected to be negligible.[5] This is because there are no variable costs associated with the standards for these engines. The market impacts associated with the program are indirect effects that stem from the impacts on the marine service markets for the larger engines that would be subject to direct compliance costs. Changes in the equilibrium outcomes in those marine service markets may lead to reductions for marine services in other marine engine and vessel markets, including the markets for smaller marine diesel engines and vessels. The result is that in some years there may be small declines in the equilibrium price in the markets for marine diesel engines less than 800 hp. This would occur because an increase in the price and a decrease in the quantity of marine transportation services provided by vessels with engines above 800 hp that results in a change in the price of marine transportation services may have follow-on effects in other marine markets and lead to decreases in prices for those markets. For example, the large vessels

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[5] The market results for engines and vessels below 800 hp are provided in a Technical Support Document that can be found in the docket for this rule.

used to provide transportation services are affected by the rule. Their compliance costs lead to a higher vessel price and a reduced demand for those vessels. This reduced demand indirectly affects other marine transportation services that support the larger vessels, and leads to a decrease in price for those markets as well.

Table 7-2. Summary of Estimated Market Impacts for 2011, 2016, 2030 (2005$)

Market	Average Variable Engineering Cost Per Unit	Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent
2011					
Rail Sector					
Locomotives	$0	-$425	-0.02%	0	-0.1%
Transportation Services	NA	NA[a]	0.1%	NA[a]	-0.1%
Marine Sector					
Engines					
C1>800 hp	$0	$0	0.00%	0	0.0%
C2>800 hp	$0	$0	0.00%	0	0.0%
Other marine	$0	$0	0.00%	0	0.0%
Vessels					
C1>800 hp	$0	$0	0.00%	0	0.0%
C2>800 hp	$0	$0	0.00%	0	0.0%
Other marine	$0	$0	0.00%	0	0.0%
Transportation Services	NA	NA[a]	0.00%	NA[a]	0.0%
2016					
Rail Sector					
Locomotives	$36,363	$35,929	1.9%	0	-0.1%
Transportation Services	NA	NA[a]	0.1%	NA[a]	-0.1%
Marine Sector [a]					
Engines					
C1>800 hp	$18,105	$17,330	11.0%	-7	-1.7%
C2>800 hp	$64,735	$64,073	24.6%	-1	-0.9%
Other marine	$0	$0	0.00%	0	0.0%
Vessels					
C1>800 hp	$2,980	$20,898	1.5%	-9	-1.7%
C2>800 hp	$6,515	$188,559	4.8%	-1	-0.9%
Other marine	$0	-$1	0.00%	-0	0.0%
Transportation Services	NA	NA[a]	0.1%	NA[a]	-0.1%
2030					
Rail Sector					
Locomotives	$50,291	$49,087	2.6%	0	-0.2%
Transportation Services	NA	NA[a]	0.4%	NA[a]	-0.2%

Market	Average Variable Engineering Cost Per Unit	Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent
Marine Sector					
Engines					
C1>800 hp	$13,885	$13,261	8.4%	-6	-1.4%
C2>800 hp	$49,360	$48,692	18.7%	-1	-0.9%
Other marine	$0	$0	0.0%	0	0.0%
Vessels					
C1>800 hp	$2,979	$16,155	1.1%	-8	-1.5%
C2>800 hp	$6,516	$141,563	3.6%	-1	-0.9%
Other marine	$0	-$4	0.0%	-2	0.0%
Transportation Services	NA	NA[a]	0.6%	NA[a]	-0.3%

[a] The prices and quantities for transportation services are normalized ($1 for 1 unit of services provided) and therefore it is not possible to estimate the absolute change price or quanitity; see 7.3.1.5.

7.1.4.2 Economic Welfare Analysis

In the economic welfare analysis we look at the costs to society of the proposed program in terms of losses to key stakeholder groups that are the producers and consumers in the rail and marine markets. The estimated surplus losses presented below reflect all engineering costs associated with the proposed program (fixed, variable, operating, and remanufacturing costs). Detailed economic welfare results for the proposed program for all years are presented in the Appendices to this chapter and are summarized below.

A summary of the estimated annual net social costs is presented in Table 7-3 and Figure 7-1. Table 7-3 shows that total social costs for each year are slightly less than the total engineering costs. This is because the total engineering costs do not reflect the decreased sales of locomotives, engines and vessels that are incorporated in the total social costs. In addition, in the early years of the program the estimated social costs of the propose program are not expected to increase regularly over time. This is because the compliance costs for the locomotive remanufacture program are not constant over time.

Table 7-3 Estimated Annual Engineering and Social Costs Through 2040 (2005$, $million)

Year	Engineering Costs						Total Social Costs
	Marine operating costs	Marine engine and vessel costs	Rail operating costs	Rail remanuf. costs	Rail new locomotive costs	Total	
2007	$0.0	$25.0	$0.0	$0.0	$3.2	$28.2	$28.2

	Engineering Costs						
2008	$0.0	$25.0	$1.3	$56.7	$3.2	$86.1	$86.1
2009	$0.0	$25.0	$1.4	$33.2	$3.2	$62.7	$62.7
2010	$0.0	$25.0	$3.8	$51.5	$7.3	$87.5	$87.5
2011	$0.0	$86.0	$7.9	$96.9	$10.8	$201.6	$201.5
2012	$0.0	$41.2	$9.7	$74.3	$12.3	$137.5	$137.5
2013	$0.0	$41.2	$12.0	$62.4	$12.3	$127.9	$127.9
2014	$2.8	$41.2	$12.6	$40.0	$16.9	$113.5	$113.5
2015	$5.6	$74.1	$14.9	$29.1	$48.8	$172.5	$172.5
2016	$14.8	$48.6	$19.0	$55.5	$55.3	$193.1	$192.6
2017	$23.9	$44.9	$32.7	$39.3	$66.5	$207.3	$206.7
2018	$36.0	$33.9	$44.6	$41.9	$67.9	$224.3	$223.9
2019	$48.0	$34.2	$56.5	$36.7	$61.9	$237.4	$236.9
2020	$60.0	$34.5	$68.5	$12.9	$64.0	$239.9	$239.5
2021	$72.0	$34.8	$80.8	$14.9	$66.2	$268.7	$268.2
2022	$83.9	$35.1	$93.6	$37.4	$68.1	$318.1	$317.6
2023	$95.7	$35.4	$106.7	$83.2	$69.8	$390.8	$390.2
2024	$107.5	$35.7	$120.1	$72.0	$70.8	$406.0	$405.4
2025	$119.1	$35.9	$133.8	$76.5	$72.5	$437.9	$437.2
2026	$130.6	$36.2	$147.7	$63.2	$73.5	$451.2	$450.4
2027	$141.9	$33.6	$161.5	$64.6	$74.7	$476.3	$475.5
2028	$153.0	$33.9	$175.5	$80.3	$75.6	$518.2	$517.3
2029	$163.3	$34.2	$189.4	$81.8	$76.3	$544.9	$544.0
2030	$172.6	$34.5	$203.3	$81.2	$76.8	$568.3	$567.3
2031	$181.2	$34.8	$217.1	$81.4	$77.6	$592.1	$591.1
2032	$189.0	$35.1	$231.1	$77.2	$78.5	$610.9	$609.8
2033	$196.4	$35.4	$244.9	$133.5	$78.9	$689.2	$688.0
2034	$203.6	$35.7	$258.7	$142.6	$79.6	$720.1	$718.8
2035	$210.4	$36.0	$272.4	$150.1	$79.8	$748.8	$747.4
2036	$216.9	$36.4	$285.8	$143.2	$77.5	$759.7	$758.3
2037	$222.7	$36.7	$299.2	$145.9	$75.8	$780.3	$778.8
2038	$227.9	$37.0	$312.0	$148.8	$73.9	$799.6	$798.1
2039	$232.4	$37.3	$324.4	$152.0	$71.8	$818.0	$816.4
2040	$236.3	$37.7	$336.3	$155.0	$69.5	$834.7	$833.2
2040 NPV at 3%[a,b]						$6,907.8	$6,896.8
2040 NPV at 7% [a,b]						$3,107.7	$3,103.1
2030 NPV at 3% [a,b]						$3,938.7	$3,932.6
2030 NPV at 7% [a,b]						$2,175.5	$2,172.5

[a] EPA EPA presents the present value of cost and benefits estimates using both a three percent and a seven percent social discount rate. According to OMB Circular A-4, “the 3 percent discount rate represents the ‘social rate of time preference’… [which] means the rate at which ‘society’ discounts future consumption flows to their present value”; “the seven percent rate is an estimate of the average before-tax rate of return to private capital in the U.S. economy … [that] approximates the opportunity cost of capital.”

[b] Note: These NPV calculations are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

Table 7-4 shows how the social costs are expected to be shared across stakeholders, for selected years. According to these results, the rail sector is expected to bear most of the costs of the program, ranging from 57.3 percent in 2011 to 67.3 percent in 2016. Producers and consumers of locomotive transportation services are expected to bear most of those costs, ranging from 51.9 percent in 2011 to 63.3 percent in 2030. As explained above, these results assume the railroads absorb all remanufacture kit compliance costs (the remanufacture kit manufacturers pass all costs of the new standards to the railroads). The marine sector is expected to bear the remaining social costs, ranging from 42.7 percent in 2011 to 32.7 percent in 2016. Producers of marine diesel engines are expected to bear more of the program costs in the early years (42.7 percent in 2011), but by 2020 producers and consumers in the marine transportation services market are expected to bear a larger share of the social costs, 31.5 percent.

Figure 7-1. Estimated Annual Social Costs, 2007-2040 (2005$, $million)

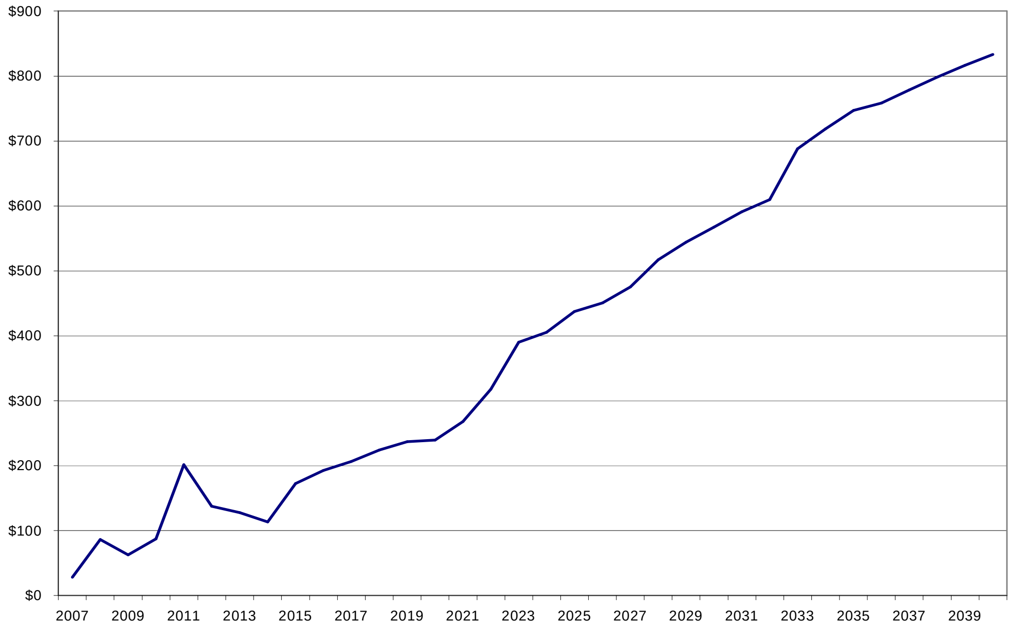

Table 7-4. Summary of Estimated Net Social Costs for 2011, 2016, 2020, 2030 (2005$, $million)

Stakeholder Group	2011		2016	
	Surplus Change	Percent	Surplus Change	Percent
Locomotives				
Locomotive producers	-$11.1	5.5%	-$13.4	7.0%
Rail transportation service providers	-$47.5	23.6%	-$52.9	27.5%
Rail transportation service consumers	-$57.0	28.3%	-$63.5	33.0%
Total locomotive sector	*-$115.6*	*57.3%*	*-$129.7*	*67.3%*
Marine				
Marine engine producers	-$86.0	42.7%	-$0.9	0.5%
C1 > 800 hp	-$22.8		-$0.7	
C2 > 800 hp	-$27.8		-$0.2	
Other marine	-$35.4		-$0.0	
Marine vessel producers	-$0	0.0%	-$18.0	9.3%
C1 > 800 hp	-$0		-$13.6	
C2 > 800 hp	-$0		-$4.4	
Other marine	-$0		-$0.0	
Recreational and fishing vessel consumers	-$0	0.0%	-$9.6	5.0%
Marine transportation service providers	-$0	0.0%	-$15.6	8.1%
Marine transportation service consumers	-$0	0.0%	-$18.7	9.7%
Total marine sector	*-$86.0*	*42.7%*	*-$62.9*	*32.7%*
TOTAL PROGRAM	-$201.5		-$192.6	

Stakeholder Group	2020		2030	
	Surplus Change	Percent	Surplus Change	Percent
Locomotives				
Locomotive producers	-$0.7	0.3%	-$1.8	0.3%
Rail transportation service providers	-$65.8	27.5%	-$163.2	28.8%
Rail transportation service consumers	-$78.9	32.9%	-$195.9	34.5%
Total locomotive sector	*-$145.3*	*60.7%*	*-$360.9*	*63.6%*
Marine				
Marine engine producers	-$0.8	0.3%	-$0.9	0.2%
C1 > 800 hp	-$0.6		-$0.7	
C2 > 800 hp	-$0.2		-$0.2	
Other marine	-$0.0		-$0.0	
Marine vessel producers	-$10.1	4.2%	-$8.2	1.4%
C1 > 800 hp	-$7.8		-$6.4	
C2 > 800 hp	-$2.3		-$1.6	
Other marine	-$0.1		-$0.1	
Recreational and fishing vessel consumers	-$7.8	3.3%	-$8.5	1.5%
Marine transportation service providers	-$34.3	14.3%	-$85.8	15.1%
Marine transportation service consumers	-$41.2	17.2%	-$103.0	18.2%
Total marine sector	*-$94.1*	*39.3%*	*-$206.5*	*36.4%*
TOTAL PROGRAM	-$239.5	100.0%	-$567.3	100.0%

Table 7-5 provides additional detail about the sources of surplus changes, for 2020 when the per unit compliance costs are stable. On the marine side, this table shows that engine and vessel producers are expected to pass along much of the engine and vessel compliance costs to the marine transportation service providers who purchase marine vessels. These marine transportation service providers, in turn, are expected to pass some of the costs to their customers. This is also expected to be the case in the rail sector.

Table 7-5. Distribution of Estimated Surplus Changes by Market and Stakeholder for 2020 (2005$, $million)

	Total Engineering Costs	**Surplus Change**
Marine Markets		
Engine Producers	*$29.3*	*–$0.8*
Vessel Producers	*$5.2*	*–$10.1*
Engine price changes		–$8.1
Equipment cost changes		–$2.0
Recreational and Fishing Consumers		*-$7.8*
Engine price changes		-$6.2
Equipment cost changes		-$1.6
Transportation Service Providers	*$60.0*	*–$34.3*
Increased price vessels		–$6.9
Operating costs		–$27.4
Users of Transportation Service		*–$41.2*
Increased price vessels		–$8.2
Operating costs		–$32.9
Rail Markets		
Locomotive Producers	*$64.0*	*–$0.7*
Rail Service Providers	*$81.4*	*–$65.8*
Increased price new locomotives		–$28.8
Remanufacturing costs	$9.5	–$8.1
Operating costs	$63.6	–$28.9
Users of Rail Transportation Service		*–$78.9*
Increased price new locomotives		–$34.6
Remanufacturing costs		–$9.7
Operating costs		–$34.7
TOTAL	***$239.9***	***$239.6***

The present value of net social costs of the proposed standards through 2040, shown in Table 7-3, is estimated to be is estimated to be \$6.9 billion (2005\$).[6] This present value is calculated using a social discount rate of 3 percent and the stream of social welfare costs from 2006 through 2040. We also performed an analysis using a 7 percent social discount rate.[7] Using that discount rate, the present value of the net social costs through 2040 is estimated to be \$3.1 billion (2005\$).

Error! Reference source not found. shows the distribution of total surplus losses for the program from 2006 through 2040. This table shows that the rail sector is expected to bear about 65 percent of the total program social costs through 2040, and that most of the costs are expected to be borne by the rail transportation service producers and consumers. On the marine side, most of the marine sector costs are expected to be borne by the marine transportation service providers and consumers. This is consistent with the structure of the program, which leads to high compliance costs for those stakeholder groups.

Table 7-6 Estimated Net Social Costs Through 2040 by Stakeholder (\$million, 2005\$)

Stakeholder Groups	Surplus Change NPV 3%	Percent of Total Surplus	Surplus Change NPV 7%	Percent of Total Surplus
Locomotives				
Locomotive producers	\$92.8	1.3%	\$63.5	2.0%
Rail transportation service providers	\$1,988.8	28.8%	\$878.1	28.3%
Rail transportation service consumers	\$2,386.4	34.6%	\$1,053.7	33.9%
Total locomotive sector	\$4,468.1	64.8%	\$1,995.4	64.4%
Marine				
Marine engine producers	\$313.3	4.5%	\$242.3	7.8%
C1 > 800 hp	\$102.1		\$73.9	
C2 > 800 hp	\$112.4		\$84.4	
Other marine	\$98.7		\$84.0	

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[6] Note: These NPV calculations are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

[7] EPA has historically presented the present value of cost and benefits estimates using both a 3 percent and a 7 percent social discount. The 3 percent rate represents a demand-side approach and reflects the time preference of consumption (the rate at which society is willing to trade current consumption for future consumption). The 7 percent rate is a cost-side approach and reflects the shadow price of capital.

Marine vessel producers	$143.8	2.1%	$71.3	2.3%
C1 > 800 hp	$110.1		$54.3	
C2 > 800 hp	$32.4		$16.5	
Other marine	$1.3		$0.5	
Recreational and fishing vessel consumers	$110.0	1.6%	$51.0	1.6%
Marine transportation service providers	$846.2	12.3%	$338.2	10.9%
Marine transportation service consumers	$1,015.4	14.7%	$405.9	13.1%
Total marine sector	$2,428.7	35.2%	$1,107.7	35.7%
TOTAL PROGRAM	$6,896.8		$3,103.1	

7.2 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 markets (prices and quantities) and stakeholder groups (producers and consumers). This is done by creating a mathematical model based on economic theory and populating the model using publicly available price and quantity data. A key factor in this type of analysis is the responsiveness of the quantity of engines, equipment, and transportation services demanded by consumers or supplied by producers to a change in the price of that product. This relationship is called the price elasticity of demand or supply.

The EIM's methodology is rooted in applied microeconomic theory and was developed following the *OAQPS Economic Analysis Resource Document*.[3] This section discusses the economic theory underlying the modeling for this EIA and several key issues that affect the way the model was developed.

7.2.1 Behavioral Economic Models

Models incorporating different levels of economic decision making can generally be categorized as *with*-behavior responses or *without*-behavior responses. The EIM is a behavioral model.

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 result is an estimate of the total compliance costs for a program. However, these models do not attempt to estimate how a regulatory program will change the prices or output of an affected industry. Therefore, the results may over-estimate the total costs of a program because they do not take decreases in quantity produced into account. In addition, engineering cost analysis does not address which stakeholders are expected to bear the costs of the regulation.

The *with*-behavior response approach builds on the engineering cost analysis and incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. As Bingham and Fox note, this framework provides "a richer story" of the expected distribution of economic welfare changes across producers and consumers.[4] In behavioral models, manufacturers of goods affected by a regulation are economic agents who 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 new regulation, consumers of the affected goods 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 resulting from the market adjustments are used to estimate the distribution of social costs between consumers and producers.

If markets are competitive and per-unit regulatory costs are small, the behavioral approach will yield approximately the same total cost impact as the engineering cost approach. However, the advantage of the *with*-behavior response approach is that it illustrates how the costs flow through the economic system and it identifies which stakeholders (producers and consumers) are most likely to be affected.

7.2.2 What is the Economic Theory Underlying the EIM?

The EIM is a multi-market partial equilibrium numerical simulation model that estimates price and quantity change in the intermediate run under competitive market conditions. Each of these model features is described in this section.

7.2.2.1 Partial Equilibrium Multi-Market Model

In the broadest sense, all markets are directly or indirectly linked in the economy, and a new regulatory program will theoretically affect all commodities and markets to some extent. However, not all regulatory programs have noticeable impacts on all markets. For example, a regulation that imposes significant per unit direct compliance costs on the production of an important manufacturing input, such as steel, would be expected to have a large impact on the national economy. However, a regulation that imposes a small direct compliance cost on an important input, or any direct compliance costs on an input that is only a small share of production costs would be expected to have less of an impact on all markets in the economy.

The appropriate level of market interactions to be included in an economic impact analysis 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. There are at least three alternative approaches for modeling interactions between economic sectors, which reflect three different levels of analysis.

In a *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. Conditions in other markets are assumed either to be unaffected by a policy or unimportant for cost estimation.

In a *multi-market* 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."[5]

In a *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.

This analysis uses a multi-market partial equilibrium approach in that it models only those markets that are directly affected by the proposed emission control program: producers and consumers in the rail and marine sectors. These two sectors are modeled separately, and the locomotive and marine components of the EIM are not linked (there is no feedback mechanism between the locomotive and marine diesel market segments; see Section 7.1.3.3). The results of the analysis will be estimated price and quantity changes in the locomotive and rail transportation services markets and in the marine engine, vessel, and transportation services markets, as well as estimates of how the compliance costs will be shared between producers and consumers in the relevant markets.

The EIM does not estimate the economic impact of the proposed emission control program on finished goods that use rail or marine transportation services as inputs. For example, while we look at the impacts of the program on locomotive transportation costs, we do not look at the impacts on electricity produced using coal transported by rail, or on manufactured productions that use that electricity. Similarly, while we look at the impacts of the control program on the price of fishing vessels, we do not look at the impacts on the prices of food products that use fish as an input. This is because these inputs (trail transportation, fishing vessel) are only a small portion of the total inputs of the final goods and services produced using them. Therefore, a change in the price of these inputs on the order anticipated by this program would not be expected to significantly affect the prices and quantities of finished products that use locomotive or marine transportation services or marine vessels as an input.

It should also be noted that the economic impact model employed for this analysis estimates the aggregate economic impacts of the control program on the relevant markets. It is not a firm-level analysis and therefore the supply elasticity or individual compliance costs facing any particular manufacturer may be different from the market average. This difference can be important, particularly where the rule affects different firms' costs over different volumes of production. However, to the extent there are differential effects, EPA believes that the wide array of flexibilities provided in this rule are adequate to address any cost inequities that may arise.

7.2.2.2 Perfect Competition Model

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). This EIM relies on an assumption of perfect competition. This means that consumers and firms are price takers and do not have the ability to influence market prices.

In a perfectly competitive market at equilibrium the market price equals the value society (consumers) places on the marginal product, as well as the marginal cost to society (producers). Producers are price takers, in that they respond to the value that consumers put on the product. It should be noted that the perfect competition assumption is not primarily about the number of firms in a market. It is about how the market operates: whether or not individual firms have sufficient market power to influence the market price. Indicators that allow us to assume perfect competition include absence of barriers to entry, absence of strategic behavior among firms in the market, and product differentiation.[8] Finally, according to contestable market theory, oligopolies and even monopolies will behave very much like firms in a competitive market if it is possible to enter particular markets costlessly (i.e., there are no sunk costs associated with market entry or exit). This would be the case, for example, when products are substantially similar (e.g., a recreational vessel and a commercial vessel).

In contrast, imperfect competition implies firms have some ability to influence the market price of output they produce. One of the classic reasons firms may be able to do this is their ability to produce commodities with 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

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[8] The number of firms in a market is not a necessary condition for a perfectly competitive market. See Robert H. Frank, Microeconomics and Behavior, 1991, McGraw-Hill, Inc., p 333.

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 and other forms of imperfect competition because the regulation exacerbates the existing 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.[6]

Perfect competition is widely accepted for this type of analysis and only in rare cases are other approaches used.[7] For the markets under consideration in this EIA we assume the perfectly competitive market structure. This is because these markets do not exhibit evidence of noncompetitive behavior: there are no indications of barriers to entry, the firms in these markets are not price setters, and there is no evidence of high levels of strategic behavior in the price and quantity decisions of the firms.

On the marine side, the markets included in this analysis do not exhibit evidence of noncompetitive behavior. On the engine side, these markets are matured, as evidenced by unit sales growing at the rate of population increases. Pricing power in such markets is typically limited. There is also excess capacity, especially on the engine side. Marine diesel engines are typically marinized land-based highway or nonroad engines, and it is possible for marine diesel engine manufacturers to produce additional marine engines with minimal production constraints if a high demand is present. On the vessel side, there are hundreds of shipyards that can be engaged in the production of vessels, and vessels from one firm can be purchased instead of engines and vessels from another firm. Finally, there are hundreds of marine transportation service providers, ranging from individuals who own their own tug or supply boat to firms that employ a fleet. It is also not uncommon for owners to move vessels among coasts and waterways to take advantage of local markets. For all of these reasons it is appropriate to model the market markets as competitive.

The locomotive markets are also modeled as competitive. While there are two main locomotive producers, EMD and GE, their products are homogeneous and railroads can easily purchase locomotives from one or the other. The high cost of fuel for the rail transportation services sector also contributes to competition among locomotive manufacturers, in that railroads will shift their purchases from one manufacturer to the other if they can achieve a reduction in fuel costs. The new switcher market will add to the competitive pressure in this market as well. On the rail transportation side, although the Government Accountability Office (GAO) has expressed concerns regarding the amount of competition in the rail road industry due to mergers over the past decades, it also acknowledges that a more “rigorous analysis of competitive markets” was needed to show the industry was not competitive.[8] The Association of American Railroads (AAR), a trade group representing the freight railroads of North America, has suggested that mergers have actually made the rail road industry more competitive. According to the AAR, most mergers have been “end-to-end” mergers that reduce the need to interchange traffic to a connecting railroad (creating a single line service), as opposed to the merger of competing railroads with parallel lines. These mergers increase competition by creating more efficient, lower cost railway networks.[9] AAR also argues that recent mergers have not given railroads excessive market power that would come with uncompetitive markets. They note that productivity is up, prices are down, innovative new operating strategies are being tested, profits are not in excess of a competitive rate of return, and they do not have an excessive share of the national transportation market.[10]

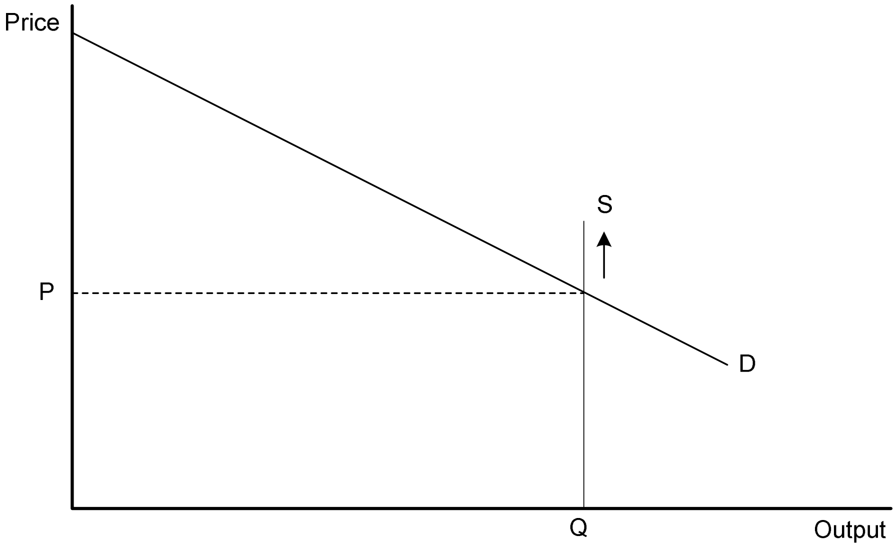
7.2.2.3 Intermediate-Run Model

In developing a multi-market 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*.[11]

The EIM models market impacts in the intermediate run. The use of the intermediate run means that some factors of production are fixed and some are variable. This modeling period allows analysis of the economic effects of the rule's compliance costs on current producers. As described below, a short-run analysis imposes all compliance costs on producers, while a long-run analysis imposes all costs on consumers. The use of the intermediate time frame is consistent with economic practices for this type of analysis.

In the very short run, all factors of production are assumed to be fixed, leaving producers with no means to respond to the increased costs associated with the regulation (e.g., they cannot adjust labor or capital inputs). 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 7-2. In essence, this is equivalent to the nonbehavioral model described earlier. Neither the price nor quantity changes 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. Although there is no hard and fast rule for determining what length of time constitutes the very short run, it is inappropriate to use this time horizon for this type of analysis because it assumes economic entities have no flexibility to adjust factors of production.

Figure 7-2. Short Run: All Costs Borne By Producers



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 (e.g., using a different labor/capital mix). Figure 7-3 illustrates a typical, if somewhat simplified, long-run industry supply function. The supply function is horizontal, indicating that the marginal and average costs of production are constant with respect to output.[9] 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.

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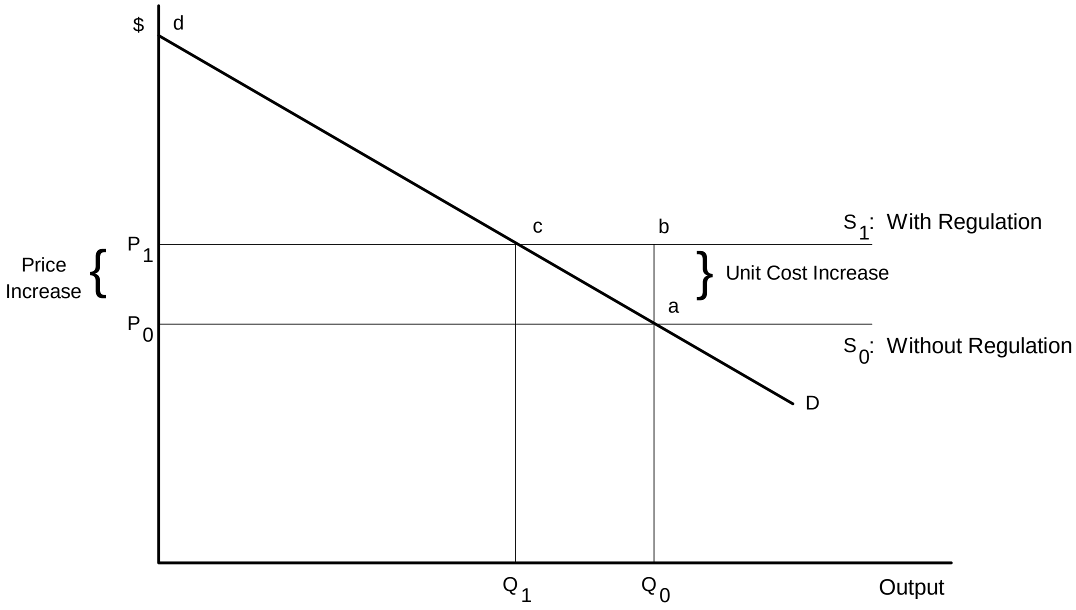
[9] The constancy of marginal costs reflects an underlying assumption of constant returns to scale of production, which may or may not apply in all cases.

Figure 7-3 Long-Run: Full-Cost Pass-Through



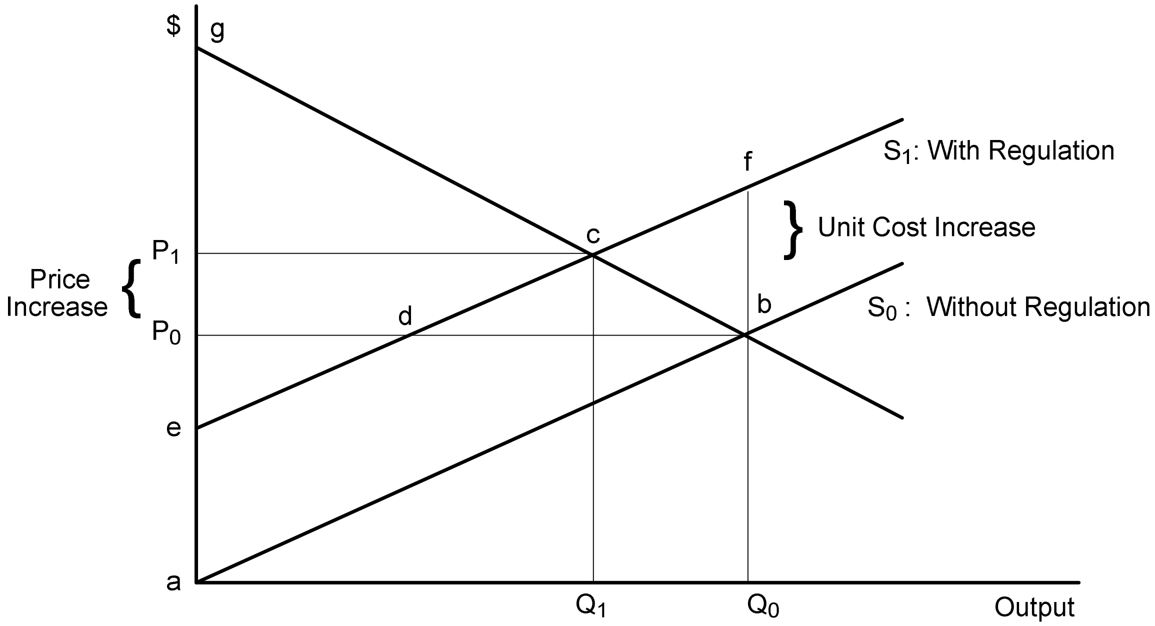
Market demand is represented by the standard downward-sloping curve. The market is assumed here to be perfectly competitive; equilibrium is determined by the intersection of the supply and demand curves. In this case, the upward shift in the market supply curve represents the regulation's effect on production 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_0ac P_1). In the nomenclature of EIAs, this long-run scenario is typically referred to as "full-cost pass-through" and is illustrated in **Error! Reference source not found.**.

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 today's entire capital equipment, 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 approach is not appropriate.

Consequently a 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 time frame allows examination of impacts of a regulatory program during the transition between the short run and the long run. In the intermediate run, there is some resource immobility which may cause producers to suffer producer surplus losses. Specifically, producers may be able to adjust some, but not all, factors of production, and they therefore will bear some portion of the costs of the regulatory program. 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 7-4.

Figure 7-4 Intermediat Run: Partial-Cost Pass-Through



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, 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.

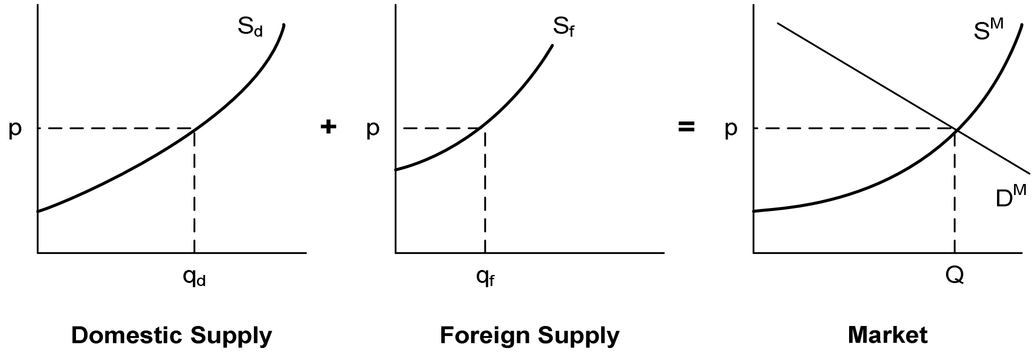
Consistent with other economic impact analyses performed by EPA, this EIM uses an intermediate run approach. This approach allows us to examine the market and social welfare impacts of the program as producers adjust their output and consumers adjust their consumption of affected products in response to the increased production costs. During this period, the distribution of the welfare losses between producer and consumer depends in large part on the relative supply and demand elasticity parameters used in the model. For example, if demand for marine vessels or locomotives is relatively inelastic (i.e., demand does not decrease much as price increases), then most of the direct compliance costs on vessel or locomotive manufacturers will be passed along to the owners and operators of this equipment in the form of higher prices.

7.2.3 How Is the EIM Used to Estimate Economic Impacts?

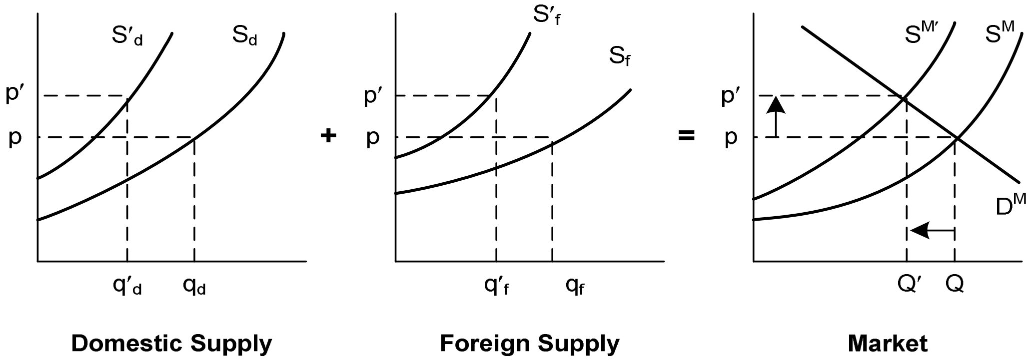
7.2.3.1 Estimation of Market Impacts (Single Market)

A graphical representation of a general economic competitive model of price formation, as shown in Figure 7-5 (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.

Figure 7-5 Market Equilibrium Without and With Regulation



a) Baseline Equilibrium



b) With-Regulation Equilibrium

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 7-5(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.

As indicated in Figure 7-5, when the proposed standards are applied the supply curve will shift upward by the amount of the estimated compliance costs. The demand curve, however, does not shift in this analysis. This is explained by the dynamics underlying the demand curve. The demand curve represents the relationship between prices and quantity demanded. Changes in prices lead to changes in the quantity demanded and are illustrated by *movements along* a constant demand curve. In contrast, changes in any of the other variables would lead to change in demand and are illustrated as *shifts* in the position of the demand curve.[10] For example, an increase in the number of consumers in a market would cause the demand curve to shift outward because there are more individuals willing to buy the good at every price. Similarly, an exogenous increase in average income would also lead the demand curve to shift outward as people choose to buy more of a good at a given price. Changes in the prices of related good and tastes or preferences can also lead to demand curve shifts.

The proposed standards are expected to increase the costs of production in all the affected markets (locomotive, rail transportation services, marine engines, marine vessels, and marine transportation services) and ultimately lead to higher equilibrium prices in the affected markets. As these prices increase, the quantity demanded falls (i.e., the price change leads to a movement along the demand curve). However, the proposed program is not expected to lead to shifts in the locomotive and marine transportation service market demand curves for several reasons. First, the demand for transportation services is determined by the national economy. The growth in the size of the national economy determines the demand for transportation services. We presume the cost of the proposed program will not change the size of the national economy in measurable ways since these sectors are relatively small contributors to GDP. Therefore, we do not expect a change in demand in these sectors. Second, the business decisions of users of rail and marine transportation services will not be changed due to the proposed program. These users will still need to use rail and marine transportation services to ship their products to their destinations for intermediate or final users of those products. In this sense, transportation services are part of an integrated production process that will not be changed by this program. For all of these reasons, it would be inappropriate to shift the demand curve for this analysis.

7.2.3.2 Incorporating Multi-Market Interactions

The above description is typical of the expected market effects for a single product markets considered in isolation (for example the locomotive or engine markets). However, the markets considered in this EIA are more complicated because of the need to investigate impacts on each component of the affected markets (engine, vessel and transportation services on the marine side and locomotives and transportation services on the locomotive side) and the relationships between those components.

For example, with regard to the commercial vessel markets, the proposed regulatory program is expected to affect vessel producers in two ways. First, these

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[10] An accessible detailed discussion of these concepts can be found in Chapters 5-7 of Nicholson's (1998) intermediate microeconomics textbook.

producers are affected by higher input costs (increases in the price of marine diesel engines) associated with the rule. Second, the standards will also impose additional production costs on vessel producers associated with vessel changes necessary to accommodate compliant engines. Similarly, the rail and marine transportation services markets will be affected by increases in the price of engines and equipment (locomotives and marine vessels) as well as direct increases in operating costs.

In the marine market case, the demand for engines is directly linked to the production of vessels that uses those engines.[11] For this reason, it is reasonable to assume that the input-output relationship between the marine diesel engines and vessels is strictly fixed and that the demand for engines varies directly with the demand for vessels. A demand curve specified in terms of its downstream consumption is referred to as a derived demand curve. Figure 7-6 illustrates how a derived demand curve is identified.

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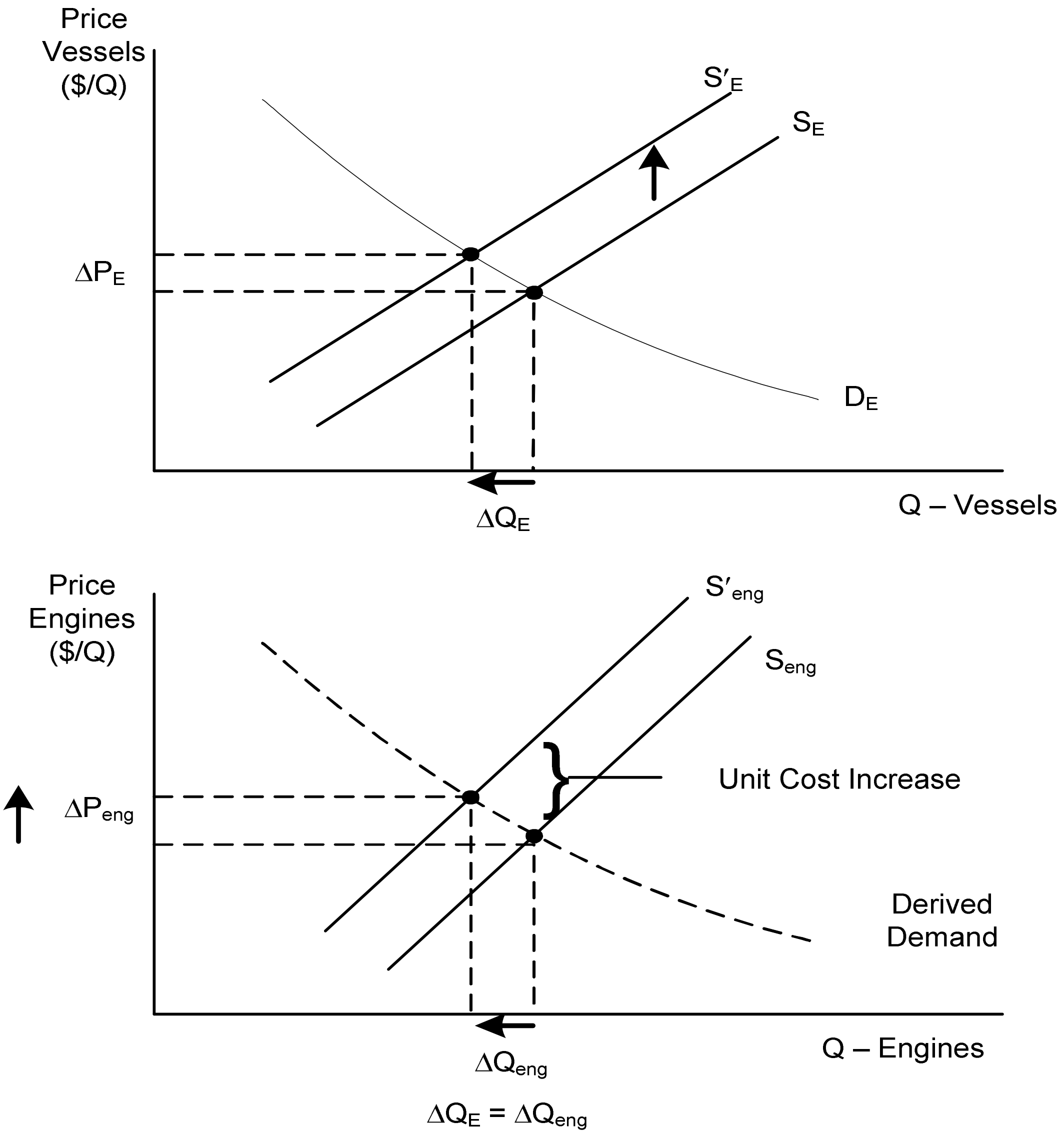
[11] In the marine vessel market, one or two engines are used per vessel, depending on its intrinsic design, and this configuration is insensitive to small changes in the engine used.

Figure 7-6 Derived-Demand Curve for Engines



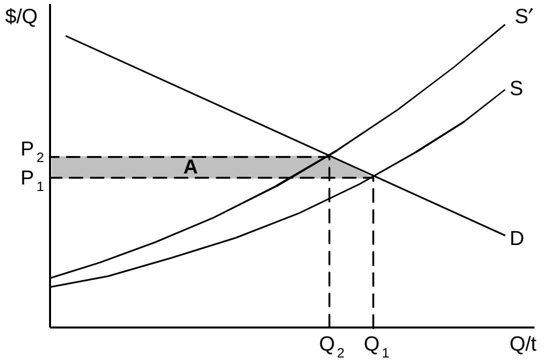
Consider an event in the marine equipment market (vessel market) that causes the price of equipment to increase by ΔP (such as an increase in the price of engines). This increase in the price of equipment will cause the supply curve in the equipment market to shift up, leading to a decreased quantity (ΔQ_E). The change in equipment production leads to a decrease in the demand for engines (ΔQ_{Eng}). 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 marine equipment markets are needed to identify the derived demand in the engine market. All of the market supply and demand curves and the elasticity parameters are described in Appendix 7F.

7.2.3.3 Estimation of Social Costs

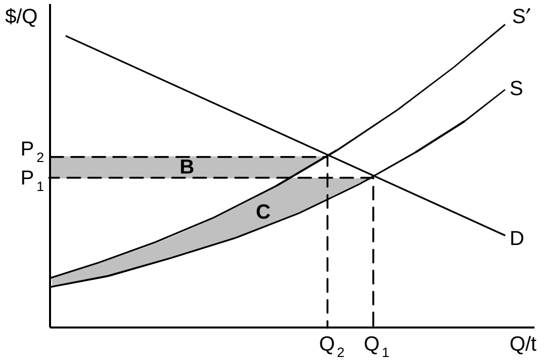
The economic welfare implications of the market price and output changes with the regulation can be examined by calculating consumer and producer net "surplus" changes associated with these adjustments. This is a measure of the negative impact of an environmental policy change and is commonly referred 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 regulation. 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 7-7).

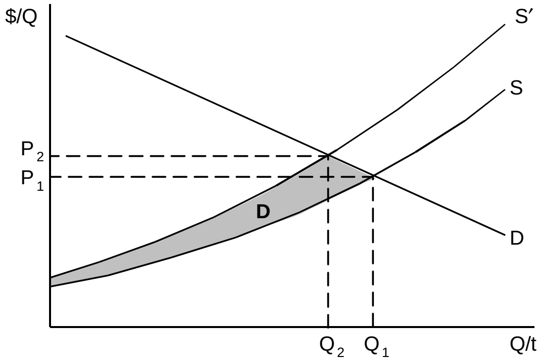
Figure 7-7. Economic Welfare Calculations: Changes in Consumer, Producer, and Total Surplus



(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 7-7, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_l with quantity Q_l. 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 7-7(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, $Q_l – Q_2$.

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 7-7(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.

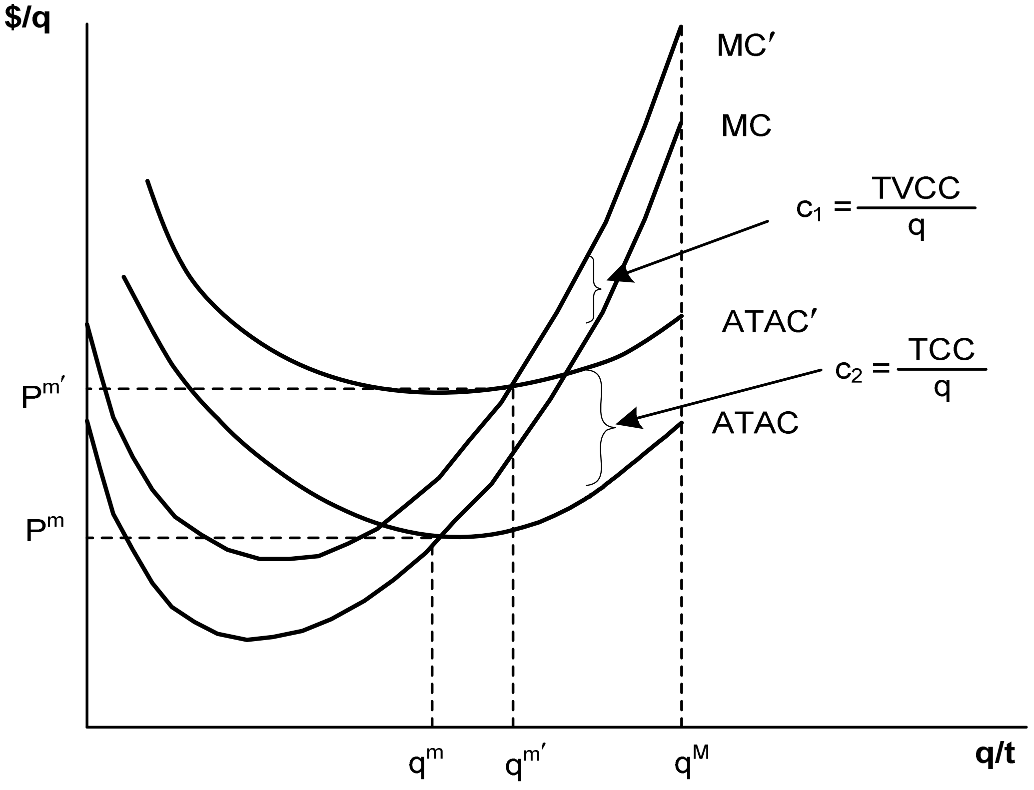
The change in economic welfare attributable to the compliance costs of the regulations is the sum of consumer and producer surplus changes, that is, –(A) + (B–C).

Figure 7-7(c) shows the net (negative) change in economic welfare associated with the regulation as area D.

7.2.3.4 Fixed and Variable Costs in a Competitive Market

The estimated engineering compliance costs, consisting of fixed costs (R&D capital/tooling, certification costs), variable costs, and operational costs provide an initial measure of total annual compliance costs without accounting for behavioral responses. The starting point for assessing the social costs and market impacts of a regulatory action is to incorporate the regulatory compliance costs into the production decision of the firm.

Figure 7-8 Modeling Fixed Regulatory Costs



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 7-8, the marginal cost (MC) curve will only be affected, or shift upwards, by the per-unit variable compliance costs (c_1=TVCC/q), while the average total cost (ATAC) curve will shift up by the per-unit total compliance costs (c_2=TCC/q). 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.

Depending on the industry type, fixed costs associated with complying with a new regulation are generally treated differently in an analysis of market impacts. In a competitive market, the industry supply curve is generally based on the market's marginal cost curve; fixed costs do not influence production decisions at the margin. Therefore, the market analysis for a competitive market is based on variable costs only.

Implicit in this approach is the assumption that manufacturers do not recover their production fixed costs by passing all or part of them to consumers through new price increases. Yet, production fixed costs must be recovered; otherwise, manufacturers would go out of business. Manufacturers in any industry are likely to have ongoing product development programs the costs of which are included in the current market price structure. It is expected that the resources for those programs would be re-oriented toward compliance with the regulatory program until those costs are recovered for each manufacturer. If this is the case, then the rule would have the effect of shifting product development resources to regulatory compliance from other market-based investment decisions. Thus, fixed costs are a cost to society because they displace other product development activities that may improve the quality or performance of engines and equipment. In this EIA, fixed costs are accounted for in the year in which they occur and are attributed to the respective locomotive, marine engine, and vessel manufacturers. These manufacturers are expected to see losses of producer surplus as early as 2007.

7.3 EIM Data Inputs and Model Solution

The EIM is a computer model comprised of a series of spreadsheet modules that simulate the supply and demand characteristics of the markets under consideration. The model equations, presented in Appendix 7E, are based on the economic relationships described in Section 7.2. The EIM analysis consists of four basic steps:

- Define the initial market equilibrium conditions of the markets under consideration (equilibrium prices and quantities and behavioral parameters; these yield equilibrium supply and demand curves).

- Introduce a policy "shock" into the model based on estimated compliance costs that shift the supply functions.

- Use a solution algorithm to estimate a new, with-regulation equilibrium price and quantity for all markets.

- 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 reflects the new market prices where total market supply equals market demand.

This section describes the markets and data used to construct the EIM: initial equilibrium market conditions (equilibrium prices and quantities), compliance cost inputs, and model elasticity parameters. Also included is a brief discussion of the solution algorithm used to estimate with-regulation market conditions.

7.3.1 Market Equilibrium Conditions

The starting point for the Economic Impact Analysis is initial market equilibrium conditions (prices and quantities) that exist prior to the implementation of the new standards. At pre-control market equilibrium conditions, consumers are willing to purchase the same amount of a product that producers are willing to produce at that market price.

7.3.1.1 Locomotive Initial Equilibrium Quantities

The EIM uses the same locomotive sales quantities that are used in the locomotive engineering cost analysis presented in Chapter 5. These sales were derived using the inputs for our locomotive emissions inventory analysis. In that analysis, we projected future locomotive populations and the number of locomotives remanufactured for given years. An estimated sales figure can be derived from those projected populations by comparing the given year’s population to the prior year’s population. The difference, after backing out the number of older locomotives that are projected to be removed from services, can be considered the new sales for the given year. Locomotive sales for all years of the analysis are contained in **Error! Reference source not found.**. Note that to be consistent with the engineering costs analysis, passenger locomotives are included with the switcher locomotives.

Table 7-7 Locomotive Sales (2007 through 2040)

Year	Line Haul Sales	Switcher/Passenger Sales
2007	646	112
2008	666	192
2009	693	128
2010	729	130
2011	751	133
2012	767	138
2013	765	251
2014	780	278
2015	816	299
2016	854	311
2017	877	332
2018	894	344
2019	917	352
2020	948	369
2021	979	387
2022	1,007	398
2023	1,034	399
2024	1,048	407
2025	1,078	401
2026	1,096	394
2027	1,119	384
2028	1,136	378
2029	1,150	370
2030	1,158	368
2031	1,173	362
2032	1,190	358
2033	1,209	316
2034	1,223	303
2035	1,231	291
2036	1,197	279
2037	1,172	267
2038	1,144	255
2039	1,112	248
2040	1,078	234

7.3.1.2 Locomotive Initial Equilibrium Prices

The price used for new line-haul locomotives used in the EIM is $2 million (2005$). The price for the switcher/passenger category is $1.3 million (2005$). These prices are based on conversations with the locomotive manufacturers. These prices are used for all years of the analysis. The analysis assumes a constant (real) price of goods and services over time and the equilibrium prices for future years are the same as the initial year equilibrium prices. This is reasonable because, in the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time (see Appendix 7G for a discussion of the constant price assumption).

7.3.1.3 Marine Engine and Vessel Initial Equilibrium Quantities

The EIM uses the same marine engine sales quantities that are used in the marine engineering cost analysis presented in Chapter 5. These are based on the Power Systems Research OELink database. The sales for 2002 are reproduced in Table 7-8.

Table 7-8. Marine Diesel Engine Sales (2002)

Marine Diesel Engine Categories (by hp)	Annual Sales Auxiliary	Annual Sales Commercial Propulsion	Annual Sales Recreational Propulsion	Total
< 50 hp[a]	9,332	67	3,924	13,323
50-200 hp	4,019	2,665	6,294	12,978
200-400 hp	1,773	1,398	2,663	5,834
400-800 hp	956	1,634	4,220	6,810
C1 800-2,000 hp	142	472	598	1,212
C1 >2,000 hp	13	196	177	386
C2 800-2,000 hp	56	6	0	62
C2 >2,000 hp	86	125	0	211
Total	16,377	6,563	17,876	40,816

[a] The cost analysis does not differentiate between auxiliary, commercial propulsion, and recreational propulsion engines <50 hp; these engines were allocated to the engine categories based on PSR OELink sales splits for 2002.

The vessel sales data for 2002 were derived by apportioning the commercial propulsion engine sales in Table 7-8 to vessel types based on current vessel populations.[12] The vessel sales are reproduced in Table 7-9.

Table 7-9. Marine Vessel Sales (2002)

Hp Bin	Fishing	Tow/Tug / Push	Ferries	Supply/ Crew	Cargo	Other Commerc'l	Recreatn'l	Total
0-50	58	0	1	0	0	1	3,924	3,983
50–200	2,293	247	40	41	13	31	6,294	8,959
200–400	601	65	10	11	3	8	1,332	2,031
400–800	703	76	12	13	4	10	2,110	2,927
C1 800–2,000	203	22	4	4	1	3	299	535
C1 >2,000	84	9	1	2	0	1	89	187

C2 800–2,000	0	1	0	1	0	0	0	3
C2 >2,000	9	27	3	15	4	1	0	58
Total	3,951	447	71	86	26	54	14,047	18,683

The marine diesel engine sales used in the EIM for 2007 through 2040 were projected by applying a 1.009 growth factor to the 2002 sales, for commercial marine diesel engines, and by applying the NONROAD model growth rate to the 2002 for recreational marine engines.

The marine vessel sales used in the EIM for 2007 through 20404 were projected by creating a ratio of engines to vessels using the 2002 data and applying that to future years engine sales. The ratios used for commercial vessels are contained in Table 7-10. Ratios were not estimated for recreational vessels because the Tier 3 standards do not require vessel modifications.[12]

Table 7-10 Ratio of Vessels to Engines

	fishing	tow	ferries	supply	cargo	other	Total
<50	0.97	0.00	0.02	0.00	0.00	0.01	1.00
50-200	0.86	0.09	0.01	0.02	0.00	0.01	1.00
200-400	0.86	0.09	0.01	0.02	0.00	0.01	1.00
400-800	0.86	0.09	0.01	0.02	0.00	0.01	1.00
800-2000	0.86	0.09	0.01	0.02	0.00	0.01	1.00
>2000	0.86	0.09	0.01	0.02	0.00	0.01	1.00
800-2000	0.15	0.46	0.04	0.26	0.07	0.01	1.00
>2000	0.15	0.46	0.04	0.26	0.07	0.01	1.00

7.3.1.4 Marine Engine and Vessel Initial Equilibrium Prices

The EIM uses baseline equilibrium engine prices for C1 commercial propulsion engines were obtained from an internet search of engine prices.[13] These prices are contained in Table 7-11. The C2 propulsion engine prices were obtained by multiplying the C1 commercial propulsion engines by about 1.5. This reflects the larger cylinder displacement of these engines and the fact that they are built for longer hours of use. The auxiliary engine prices were derived by dividing the propulsion engine prices by 2. This is because auxiliary marine diesel engines are often more similar to land-based engines and don't require the same types of modifications for use in the marine environment.

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[12] This EIA was based on an earlier version of the cost analysis that did not include compliance costs for recreational vessels >2000 kW.

They are also designed to operate at constant load and don't see the transients experienced by propulsion engines. The recreational engine prices were derived by multiplying the propulsion engines by 1.25, reflecting the fact that while recreational engines are often similar to commercial engines they are designed for higher power and use at higher engine load. Recreational engines also often have esthetic features (e.g., chrome fixtures) that set them apart from their recreational counterparts.

Table 7-11. Per Unit Marine Diesel Engine Prices (2005$)

Marine Diesel Engine Categories (by hp)	Commercial Propulsion	Recreational	Auxiliary
< 50 hp	$7,000	$8,750	$3,500
50-200 hp	$16,000	$20,000	$8,000
200-400 hp	$21,000	$26,250	$10,500
400-800 hp	$50,000	$62,500	$25,000
C1 800-2,000 hp	$155,000	$193,750	$77,500
C1 > 2,000 hp	$300,000	$375,000	$150,000
C2 800-2,000 hp	$230,000	NA	$115,000
C2 > 2,000 hp	$450,000	NA	$225,000

The baseline equilibrium marine vessel prices used in the EIM were derived from the engine prices by applying an assumed ratio of the price of the vessel to the price of the propulsion engines onboard. Table 7-12 sets out the ratios used to estimate the vessel prices, and Table 7-13 sets out the vessel prices used in the EIA.

Table 7-12. Ratio of Vessel Price to Marine Diesel Engine Price

Hp Bin	Fishing	Tow/Tug/ Push Boat	Ferries	Supply/ Crew	Cargo	Other Commercial	Recreational
0-50	5		6			5	6
50-200	5	6	6	6	6	5	6
200-400	3.5	4	4	8	4	3.5	4
400-800	3.5	4.5	4.5	9	4.5	3.5	4
C1 800-2,000	3.5	5	5	10	10	3.5	4
C1 >2,000	3.5	5	5	10	10	3.5	4
C2 800-2,000	3.5	5	5	10	10	3.5	4
C2 >2,000	3.5	5	5	10	10	3.5	4

Table 7-13. Per Unit Marine Vessel Prices (2005$)

Hp Bin	Fishing	Tow/Tug/ Push Boat	Ferries	Supply/ Crew	Cargo	Other Commercial	Recreational
0-50	$35,000		$42,000			$35,000	$52,500
50-200	$80,000	$96,000	$96,000	$96,000	$96,000	$80,000	$120,000
200-400	$147,000	$168,000	$168,000	$336,000	$168,000	$147,000	$210,000

400-800	$350,000	$450,000	$450,000	$900,000	$450,000	$350,000	$500,000
C1 800-2,000	$1,085,000	$1,550,000	$1,550,000	$3,100,000	$3,100,000	$1,085,000	$1,550,000
C1 >2,000	$2,100,000	$3,000,000	$3,000,000	$6,000,000	$6,000,000	$2,100,000	$3,000,000
C2 800-2,000	$1,610,000	$2,300,000	$2,300,000	$2,300,000	$4,600,000	$1,610,000	NA
C2 >2,000	$3,150,000	$4,500,000	$4,500,000	$4,500,000	$9,000,000	$3,150,000	NA

With respect to future prices, this analysis assumes a constant (real) price of goods and services over time and the equilibrium prices for future years are the same as the baseline equilibrium prices. This is reasonable because, in the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time (see Appendix 7G for a discussion of the constant price assumption).

7.3.1.5 Baseline Quantities and Equilibrium Prices for Transportation Markets

The nature of the locomotive and marine transportation services markets makes it difficult to identify the baseline equilibrium prices and quantities for this analysis. Instead of trying to estimate these values, the EIM uses an alternative approach based on total revenues for each sector. In this approach, annual revenue data is used as a proxy for production data. This data is normalized such that the baseline price is set equal to $1/unit and the baseline quantity is then equal to the annual revenue. This allows estimation of the relative price change and the relative quantity change due to the proposed program, although it does not allow estimation of the absolute price and absolute quantity change.

Baseline data for the EIM's railroad and marine service revenues are reported in Table 7-13. Revenue data for the rail transportation services freight revenue comes from the Association of American Railroads Freight Railroad Statistics, Condensed Income Statement, revenue for freight and passenger services.[14] Revenue data for the marine transportation services sector comes from the U.S. Census reports revenues for the marine service sector for 2002.[13] Revenue data for 2002 was obtained for the following NAICS codes: 483113 (coastal & great lakes freight), 483114 (coastal & great lakes passenger), 4832 (inland water transportation), 4872(Scenic & sightseeing transportation, water), plus a portion of 4883 (support activity for water transportation). The 2002 revenue data was adjusted for 2005 using the GDP deflator index.

Table 7-14. Railroad and Marine Service Markets Baseline Revenue Data ($billions)

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[13] We adjusted marine transportation service revenue to reflect 2005 dollars using the latest GDP deflator.

Transportation Service Market	2002	Annual Growth Rate	2005
Railroad Services Market	NR	0.9%	$44.5
Marine Services Market	$13.8	0.9%	$14.2

To estimate production for 2005, we applied growth rates used for engine sales. Revenue for all future years of the analysis (2007 to 2040) were calculated by applying annual growth rates to the 2005 data set as follows:

$$\text{Revenue}_{200X} = \text{Revenue}_{2005} \times (1+0.009)^{(200X-2005)}$$

This data suggests that the rail transportation sector is much larger than the marine transportation sector. However, the difference in the amount of tons of goods moved is smaller. According to AAR, the rail transportation sector moved about 1,844.2 million tons of freight in 2004.[15] The marine sector accounted for about 1,047.1 million tons in that year.[16] So, while some of the difference in revenue is due to differences in the amount of freight transported, part of the difference is due to differences in the characteristics of each sector. For example, railroads are responsible for maintaining the rail system; they pass some of those costs to their customers through higher prices. The marine system, in contrast, is maintained by public authorities (U.S. Army Corps of Engineers, state and local governments), and so those costs would not be reflected in the prices of marine transportation services. Similarly, while rail yards are maintained by railroads, ports are owned and operated by various public and private authorities. Finally, marine transportation is somewhat more fuel efficient than rail, with one tug or towboat able to transport more goods than one locomotive.

7.3.2 Compliance Costs

The social costs of the proposed standards are estimated by shocking the initial market equilibrium conditions by the amount of the compliance costs. The EIM uses an earlier version of the engineering costs developed for this rule (see Section 7.1.4 above).

Table 7-15 summarizes how the compliance costs are applied to each component of the EIM to simulate the effect of the emission control program. There are no compliance costs for the demand side of these markets. This is because the program does not regulate consumers or impose direct compliance costs on them (see also Section 7.2.3.1).

Table 7-15. Summary of Types of Compliance Costs

Market	Category	Supply Shift			Demand Shift
		Entity	Direct Costs	Indirect Costs	
Rail	Locomotive	Loco Mfr	Variable costs	N/A	No demand

	Transportation Services	Railroad	Urea, Fuel, remanufacture kit	Higher locomotive prices	shift; see 7.2.3.1
Marine	<800 hp	Engine Mfr	Variable costs = 0	N/A	
		Vessel	Variable costs = 0	Higher engine prices	
	>800 hp	Engine mfr	Variable costs	N/A	
		Vessel	Variable costs	Higher engine prices	
	Transportation Services	Vessel Owner	Urea, fuel	Higher engine and vessel prices	

The compliance costs used in the EIM are based on the estimated engineering compliance costs described in Chapter 5. For marine diesel engine variable costs, we used the piece costs shown in Table 5-29 with a couple of exceptions. First, the EIA contains costs for closed crankcase ventilation systems which were subsequently removed from the cost analysis presented in Chapter 5. Second, the engine-related hardware costs here in the EIA do not include costs associated with urea SCR tanks and brackets which, we decided, should be considered vessel related hardware costs for the EIA. For marine diesel engine fixed costs in the EIA, we simply divided the annual engine fixed costs by the projected sales for the given year, rather than using the present value per engine costs presented in several tables throughout section 5.2.1. This makes the fixed costs per engine appear rather large in the EIA since those costs are being spread over a relatively small number of engines (only a few years of sales).

On the vessel side, we used the vessel hardware costs shown in Table 5-38, and added to that the costs for urea SCR tanks and brackets. Importantly, the costs associated with the urea tank and brackets are incurred for every engine (auxiliary and propulsion), while the vessel hardware costs shown in Table 5-38 are incurred for every vessel. To arrive at a per vessel cost for the EIA, we multiplied the urea tank and bracket costs by the projected number of engines (auxiliary and propulsion) and then divided by the projected number of vessels, then added the vessel hardware costs shown in Table 5-38. In the end, the vessel hardware costs presented here look different than those presented in Chapter 5 due to different accounting, but the total costs are not affected by that accounting difference. The vessel fixed costs are the annual redesign costs divided by the projected number of vessel sales during the given years. Note that the annual fixed costs have been allocated to power ranges based on the percentage of engines within the appropriate power range. Also note that the per-unit cost estimates are based on an average of 1.5 propulsion engines per vessel.

For locomotives, we used essentially the same methodology. The variable costs are taken from Tables 5-29 and 5-38, with the same difference associated with closed crankcase ventilation system costs noted above. Annual fixed costs are simply divided by the sales for the given year making them, once again, appear rather large on a per locomotive basis here in the EIA. In the EIA, since the locomotive and its engine are considered to be one in the same, there was no need to differentiate between purely engine costs and equipment costs.

For all markets, fixed costs are allocated to the year in which they occur. For this analysis, fixed costs are spread over five years in advance of the applicable standards with the exception of certification costs, which are allocated to the year before the standards are effective. Variable costs begin to be incurred only when the programs go into effect. For locomotives and marine diesel engines, this means a staggered set of fixed costs, as described in Table 7-16, with the compliance costs for the different Tiers overlapping in some years. It should be remembered that the EIA is based on an earlier version of the cost analysis and may not reflect changes to the way in which costs are allocated for the proposed program as described in Chapter 5. For marine vessels, there are no compliance costs associated with the Tier 3 standards since they are engine-based controls and will not affect the footprint of the engine. The marine vessel compliance costs for Tier 4 begin in 2015 and are incurred over a 15-year period that is derived from the number of vessel types that will have to be modified (see Chapter 5 for an explanation of how vessel costs are allocated; note that the final costs in Chapter 5 reflect these costs distributed over a shorter period).

Table 7-16 Locomotive and Marine Engine Compliance Costs Schedule

	Loco T3	Loco T4 PM	Loco T4 NO_x	Marine T3	Marine T4
2007	✓			✓	
2008	✓			✓	
2009	✓			✓	
2010	✓	✓		✓	
2011	✓	✓		✓	✓
2012	Effective Date	✓	✓	Effective Date	✓
2013		✓	✓		✓
2014		✓	✓		✓
2015		Effective Date	✓		✓
2016			✓		Effective Date
2017			Effective Date		

7.3.2.1 Locomotive Compliance Costs

The estimated per unit compliance costs for new locomotives used in the EIM are summarized in Table 7-17. These costs are dominated by fixed costs in the early years of the program. Variable costs do not occur until 2015, when the aftertreatment standards begin. This reflects the fact that there are no variable costs associated with the Tier 3 standards. Fixed costs reflect both the Tier 3 and Tier 4 costs. There is some overlap in these two programs, with the Tier 3 fixed costs applying in 2007 through 2011, and the Tier 4 fixed costs applying in 2010 through 2016. The latter period represents 5 years of fixed costs for the PM aftertreatment standards (2010 through 2014) and 5 years of fixed costs for the NO_x aftertreatment standards (2012 through 2016).

Table 7-17 Estimated Per Unit Compliance Costs – New Locomotives (2005$)

	Line Haul Locomotive			Switcher, Passenger Locomotive		
Year	Variable	Fixed	Total	Variable	Fixed	Total
2007	$0	$991	$991	$0	$22,767	$22,767
2008	$0	$991	$991	$0	$13,304	$13,304
2009	$0	$923	$923	$0	$19,938	$19,983
2010	$0	$3,197	$3,197	$0	$37,929	$37,929
2011	$0	$5,134	$5,134	$0	$51,419	$51,914
2012	$0	$6,678	$6,678	$0	$52,200	$52,200
2013	$0	$6,694	$5,694	$0	$28,777	$28,777
2014	$0	$9,329	$9,239	$0	$35,031	$35,031
2015	$44,390	$4,204	$48,594	$14,353	$16,179	$30,531
2016	$44,390	$6,465	$50,855	$14,353	$23,603	$37,956
2017	$68,544	$0	$68,544	$19,230	$0	$19,230
2018	$68,544	$0	$68,544	$19,230	$0	$19,230
2019+	$60,624	$0	$60,624	$17,770	$0	$19,230

7.3.2.2 Marine Diesel Engine Compliance Costs

The estimated per unit compliance costs for new marine diesel engines used in the EIM are summarized in Table 7-18 (C2 engines), Table 7-19 (C1 engines), Table 7-20 (recreational engines), and Table 7-21 (small engines). In the early years, 2007 through 2011, there are fixed costs associated with the Tier 3 standards. Beginning in 2012, there are no compliance costs associated with the Tier 3 standards. The Tier 4 standards apply only to engines above 800 hp. As a result, there are fixed costs attributed to those engines through 2015, after which time the only costs are variable costs associated with the aftertreatment devices.[14] Because this EIA is uses an earlier version of the compliance costs estimates that did not include Tier 4 standards for recreational engines above 2,000 kW, the costs for those engines and vessels are not included in these tables.

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[14] It should be noted that there is an inconsistency in the cost analysis, which applies the operational costs for these C2 engines in 2014 but does not include the compliance costs for engines or vessels until later years. While this affects the individual year results for early years, the differences disappear by 2016 by which year all marine diesel engines above 800 hp have aftertreatment standards.

Table 7-18 Estimated Per Unit Compliance Costs - C2 Commercial Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$14,571	$14,441	$14,312	$14,184	$93,647	$69,382
	Total	$14,571	$14,441	$14,312	$14,184	$93,647	$69,382
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$14,571	$14,441	$14,312	$14,184	$93,647	$69,382
	Total	$14,571	$14,441	$14,312	$14,184	$93,647	$69,382

Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
800-2,000	Variable	$0	$0	$0	$39,059	39,059	29,827
	Fixed	$68,763	$68,150	$97,398	$0	$0	$0
	Total	$68,763	$68,150	$97,398	$39,059	39,059	29,827
>2,000	Variable	$0	$0	$0	$72,301	$72,301	$55,121
	Fixed	$68,763	$68,150	$97,398	$0	$0	$0
	Total	$68,763	$68,150	$97,398	$72,301	$72,301	$55,121

Table 7-19 Estimated Per Unit Compliance Costs – C1 Commercial Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$836	$829	$822	$814	$1,475	$0
	Total	$836	$829	$822	$814	$1,475	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$836	$829	$822	$814	$1,475	$0
	Total	$836	$829	$822	$814	$1,475	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$836	$829	$822	$814	$1,475	$0
	Total	$836	$829	$822	$814	$1,475	$0
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$2,033	$2,015	$1,997	$1,979	$25,553	$22,720
	Total	$2,033	$2,015	$1,997	$1,979	$25,553	$22,720
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$2,033	$2,015	$1,997	$1,979	$25,553	$22,720
	Total	$2,033	$2,015	$1,997	$1,979	$25,553	$22,720

Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
50-200	Variable	$0	$0	$0	$0	$0	$0

	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$0	$0	$15,319	$15,319	$11,763
	Fixed	$22,517	$22,316	$28,928	$0	$0	$0
	Total	$22,517	$22,316	$28,928	$15,319	$15,319	$11,763
>2,000	Variable	$0	$0	$0	$26,296	$26,926	$20,116
	Fixed	$22,517	$22,316	$28,928	$0	$0	$0
	Total	$22,517	$22,316	$28,928	$26,296	$26,926	$20,116

Table 7-20 Estimated Per Unit Compliance Costs – Recreational Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$403	$393	$384	$375	$684	$0
	Total	$403	$393	$384	$375	$684	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$403	$393	$384	$375	$684	$0
	Total	$403	$393	$384	$375	$684	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$403	$393	$384	$375	$684	$0
	Total	$403	$393	$384	$375	$684	$0
800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$403	$393	$384	$375	$684	$0
	Total	$403	$393	$384	$375	$684	$0
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$403	$393	$384	$375	$684	$0
	Total	$403	$393	$384	$375	$684	$0
Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
50-200	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0

800-2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0
>2,000	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0

Table 7-21 Estimated Per Unit Compliance Costs – Small Marine Engines (2005$)

Hp Category	Cost Type	2007	2008	2009	2010	2011	2012
0-50	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$126	$124	$123	$122	$245	$0
	Total	$126	$124	$123	$122	$245	$0
Hp Category	Cost Type	2013	2014	2015	2016	2017	2018+
0-50	Variable	$0	$0	$0	$0	$0	$0
	Fixed	$0	$0	$0	$0	$0	$0
	Total	$0	$0	$0	$0	$0	$0

7.3.2.3 Marine Vessel Compliance Costs

The estimated per unit compliance costs for marine vessels used in the EIM are summarized in Table 7-22 (C2 vessels, i.e., vessels with a C2 main propulsion engine), Table 7-23 (C1 vessels, i.e., vessels with a C1 main propulsion engine), **Error! Reference source not found.** (recreational vessels), and **Error! Reference source not found.** (small marine vessels). There are no vessel compliance costs associated with the Tier 3 standards. This means there are no vessel compliance costs at all for recreational vessels or Small vessels (those with a propulsion engine below 50 hp). This is because the Tier 3 engine footprint is not expected to be modified from the Tier 2 configuration. The sole vessel compliance costs are those associated with the Tier 4 aftertreatment standards. These begin in 2015, with the fixed costs, which continue through 2027.[15] Variable costs begin in 2016 and continue for all years of the analysis. Because this EIA is uses an earlier version of the compliance costs estimates that did not include Tier 4

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[15] It should be noted that there is an inconsistency in the cost analysis, which applies the operational costs for these C2 engines in 2014 but does not include the compliance costs for engines or vessels until later. years. While this affects the individual year results for early years, the differences disappear by 2016 by which year all marine diesel engines above 800 hp have aftertreatment standards.

standards for recreational engines above 2,000 kW, the costs for those engines and vessels are not included in these tables.

Table 7-22 Per Unit Compliance Costs – C2 Vessels (2005$)

Hp Category	Cost Type	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2027	2028	2029+
50-200	Variable	$0	$0	$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	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$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	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$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	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964	$3,964
	Fixed	$50,000	$29,732	$19,645	$9,735	$9,648	$9,562	$9,477	$9,392	$9,308	$9,225	$9,143	$9,061	$0	$0
	Total	$50,000	$33,697	$23,609	$13,699	$13,612	$13,526	$13,441	$13,356	$13,273	$13,190	$13,107	$13,026	$3,964	$3,964
>2,000	Variable	$0	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155	$7,155
	Fixed	$50,000	$29,732	$19,645	$9,735	$9,648	$9,562	$9,477	$9,392	$9,308	$9,225	$9,143	$9,061	$0	$0
	Total	$50,000	$36,887	$26,799	$16,889	$16,803	$16,716	$16,631	$16,547	$16,463	$16,380	$16,298	$16,216	$7,155	$7,155

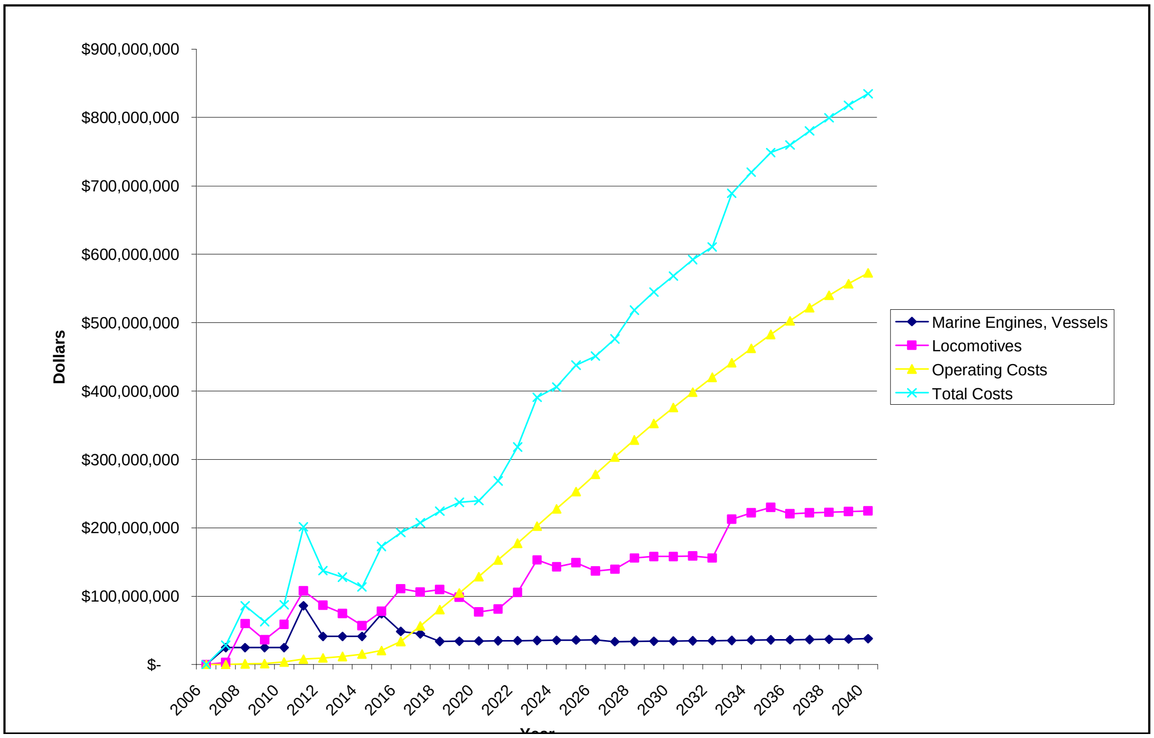
Table 7-23 C1 Per Unit Compliance Costs – C1 Vessels (2005$)

Hp Category	Cost Type	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2027	2028	2029+
50-200	Variable	$0	$0	$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	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
200-400	Variable	$0	$0	$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	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
400-800	Variable	$0	$0	$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	$0	$0
	Total	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
800-2,000	Variable	$0	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385	$2,385
	Fixed	$25,000	$12,884	$6,876	$3,894	$3,859	$3,825	$3,791	$3,757	$3,723	$3,690	$3,657	$3,625	$0	$0
	Total	$25,000	$15,269	$9,261	$6,279	$6,244	$6,210	$6,176	$6,142	$6,108	$6,075	$6,042	$6,010	$2,385	$2,385
>2,000	Variable	$0	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672	$4,672
	Fixed	$25,000	$12,884	$6,876	$3,894	$3,859	$3,825	$3,791	$3,757	$3,723	$3,690	$3,657	$3,625	$0	$0
	Total	$25,000	$17,556	$11,547	$8,565	$8,531	$8,496	$8,462	$8,428	$8,395	$8,362	$8,329	$8,296	$4,672	$4,672

7.3.2.4 Operating Costs

There are two types of operating costs that are affected by the control program: the additional costs associated with operating vessels and locomotives equipped with the emission control technologies that would be required by the program, and the additional costs associated with the locomotive remanufacture program.

Figure 7-9. Estimated TotalCompliance Costs by Type, 2007-2040



Operating Costs. As explained in Chapter 5, we anticipate three sources of increased costs associated with operating vessels and locomotives equipped with the emission control technologies that would be required by the program: urea use, DPF maintenance, fuel consumption. The costs associated with urea use would affect only those locomotives or vessels equipped with a urea SCR engine. Maintenance costs associated with the DPF (for periodic cleaning of accumulated ash resulting from unburned material that acculuates in the DPF) would occur only in those locomotives or vessels equipped with a DPF engine. Thus, those costs are limited to Tier 4 engines. The fuel consumption impact is expected to occur more broadly, for both Tier 4 locomotives and engines and for remanufactured Tier 0 locomotives. As illustrated in Figure 7-9, the estimated operating costs are substantial when compared with the compliance costs associated with engine and equipment modifications.

The EIM applies the operational costs to the rail and marine transportation services markets, by shifting the transportation service sector supply curves by the amount of the operating costs for that sector for that year. This was done by dividing the total operating costs for each service sector by the revenue for that year, where revenue represents the quantity produced in each service sector (due to normalized costs; see 7.3.1.4). The operating costs per unit are then interpreted as costs per dollar of output.

Applying these costs to the locomotive transportation market, in the rail sector case, is appropriate because all locomotives built after the Tier 4 standards go into effect will incur these operating costs. On the marine side, the EIM uses a simplifying assumption that applies all marine operating costs to the marine transportation services market. This approach was taken because the operating costs (fuel and urea consumption) were estimated based on fuel consumption and we believe that most of the fuel consumed in the marine sector is by vessels in the marine transportation services sector. While many of the new non-recreational vessels built each year are fishing vessels, the use of fishing vessels is highly seasonal and hence they would not be expected to use as much fuel as the other commercial vessels (tug/tow/pushboats, ferries, cargo vessels, and supply/crew boats) that are used extensively all year around. As a result of this assumption, the impacts on the marine transportation service market may be somewhat over-estimated.

Table 7-24 Marine and Locomotive Operating Costs 2007-2040 (2005$)

	Marine C1>800Hp	Marine C2	Loco-Line haul	Loco-Switcher & Passenger	Total
2006	$0	$0	$0	$0	$0
2007	$0	$0	$0	$0	$0
2008	$0	$0	$1,221,312	$40,179	$1,261,491
2009	$0	$0	$1,210,900	$160,835	$1,371,735
2010	$0	$0	$3,515,299	$280,687	$3,795,986
2011	$0	$0	$7,551,076	$392,336	$7,943,411
2012	$0	$0	$9,225,485	$435,933	$9,661,419
2013	$0	$0	$11,514,508	$472,292	$11,986,800
2014	$0	$2,811,138[a]	$12,052,336	$501,894	$15,365,368
2015	$0	$5,629,325[a]	$14,325,890	$559,055	$20,514,270
2016	$3,748,711	$11,007,676	$18,337,278	$670,590	$33,764,256
2017	$7,493,511	$16,385,211	$30,926,013	$1,737,068	$56,541,803
2018	$14,199,915	$21,762,262	$41,788,824	$2,767,721	$80,518,723
2019	$20,882,573	$27,139,987	$52,700,319	$3,820,549	$104,543,428
2020	$27,527,317	$32,504,807	$63,571,104	$4,915,367	$128,518,594
2021	$34,133,758	$37,868,806	$74,765,580	$6,052,613	$152,820,757
2022	$40,682,747	$43,220,176	$86,363,005	$7,215,420	$177,481,347
2023	$47,173,642	$48,558,846	$98,350,736	$8,390,480	$202,473,704
2024	$53,573,572	$53,885,232	$110,512,199	$9,592,182	$227,563,184
2025	$59,881,593	$59,200,774	$123,059,778	$10,783,930	$252,926,074
2026	$66,065,578	$64,518,680	$135,694,126	$11,963,396	$278,241,780
2027	$72,088,258	$69,826,073	$148,437,564	$13,108,658	$303,460,553
2028	$77,882,344	$75,125,645	$161,217,797	$14,247,139	$328,472,925

	Marine C1>800Hp	Marine C2	Loco-Line haul	Loco-Switcher & Passenger	Total
2029	$82,861,888	$80,389,769	$174,009,828	$15,376,721	$352,638,206
2030	$86,995,449	$85,630,509	$186,753,267	$16,509,822	$375,889,047
2031	$90,362,827	$90,821,351	$199,510,957	$17,637,122	$398,332,257
2032	$93,020,024	$95,974,911	$212,291,194	$18,764,807	$420,050,936
2033	$95,380,145	$101,051,358	$225,111,725	$19,796,404	$441,339,632
2034	$97,498,765	$106,062,320	$237,920,399	$20,801,857	$462,283,341
2035	$99,411,516	$110,968,576	$250,602,975	$21,784,330	$482,767,397
2036	$101,151,649	$115,727,740	$263,081,520	$22,741,774	$502,702,683
2037	$102,751,192	$119,955,873	$275,486,662	$23,684,289	$521,878,016
2038	$104,242,148	$123,625,344	$287,475,707	$24,563,660	$539,906,858
2039	$105,628,120	$126,752,201	$299,021,332	$25,393,609	$556,795,262
2040	$106,922,034	$129,386,543	$310,117,313	$26,160,790	$572,586,680

[a] It should be noted that there is an inconsistency in the cost analysis, which applies the operational costs for these C2 engines in 2014 but does not include the compliance costs for engines or vessels until later years. While this affects the individual year results for early years, the differences disappear by 2016 by which year all marine diesel engines above 800 hp have aftertreatment standards.

Remanufacturing Costs. Railroads are also subject to costs associated with the periodic remanufacturing of their locomotives. They are currently required to use certified remanufacture kits when they rebuild engines originally built in 1973 through 2001 (called Tier 0 locomotives). This program will extend the remanufacturing requirements both to tighten the standards associated with Tier 0 locomotives and to add requirements for engines built after 2001 (Tier 1 and Tier 2 locomotives). In the EIM, these remanufacture costs are treated as operating costs and applied to the railroads along with their urea costs. This approach was chosen because these costs are periodic and recurring. Specifically, they apply to every engine, but only at five to seven year intervals. An important consequence of this modeling approach is that it assumes that the locomotive owner bears the full cost of the remanufacturing kit and the kit provider does not bear any of the cost. However, we believe this simplifying assumption is appropriate. The mandatory nature of the requirement would result in a price elasticity of demand that is close to zero (inelastic) because if a railroad owns a Tier 0, Tier 1, or Tier 2 locomotive it very simply must purchase a kit or it can no longer operate the locomotive. The cost of a remanufacture kit would have to be very high before the option of pulling the locomotive out of service or purchasing a new one would become attractive.

As explained in Chapter 5, the remanufacturing costs for Tier 0 and Tier 1 locomotives represent the difference between the cost of current remanufacture kits and those that will be required pursuant to the standards. For these kits, first time rebuilds will require additional fuel system components that are not required in subsequent rebuilds and therefore the cost for the initial rebuild is more than for future rebuilds. For Tier 2 locomotives, there are additional costs for the initial rebuild, but not for future rebuilds. There are no additional costs associated with Tier 3 rebuilds because these locomotives have all of the essential components when they are built new. Finally, there are rebuild costs for Tier 4 locomotives associated with the aftertreatment devices. Tier 4 locomotives begin to be rebuilt in 2023.

There is no corresponding remanufacture requirement for marine diesel engines (see Chapter 8 for a discussion of a programmatic alternative that would set such a requirement in place for marine diesel engines above 800 hp).

Table 7-25 Per Unit Locomotive Remanufacture Costs – Line Haul

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
2007	$0	$0	$0	$0	$0
2008	$33,800	$0	$0	$0	$0
2009	$33,800	$33,800	$0	$0	$0
2010	$33,800	$33,800	$0	$0	$0
2011	$33,800	$33,800	$0	$0	$0
2012	$33,800	$33,800	$0	$0	$0
2013	$33,800	$33,800	$11,749	$0	$0
2014	$33,800	$33,800	$11,749	$0	$0
2015	$33,800	$33,800	$11,749	$0	$0
2016	$33,800	$33,800	$11,749	$0	$0
2017	$22,300	$22,300	$11,749	$0	$0
2018	$22,300	$22,300	$11,749	$0	$0
2019	$22,300	$22,300	$11,749	$0	$0
2020	$22,300	$22,300	$0	$0	$0
2021	$22,300	$22,300	$0	$0	$0
2022	$22,300	$22,300	$0	$0	$0
2023+	$22,300	$22,300	$0	$0	$66,421

Table 7-26 Per Unit Locomotive Remanufacture Costs – Switcher and Passenger

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
2007	$0	$0	$0	$0	$0
2008	$33,800	$33,800	$0	$0	$0
2009	$33,800	$33,800	$0	$0	$0
2010	$33,800	$33,800	$0	$0	$0
2011	$33,800	$33,800	$0	$0	$0
2012	$33,800	$33,800	$0	$0	$0

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
2013	$33,800	$33,800	$0	$0	$0
2014	$33,800	$33,800	$0	$0	$0
2015	$33,800	$33,800	$8,728	$0	$0
2016	$33,800	$33,800	$8,728	$0	$0
2017	$22,300	$22,300	$8,728	$0	$0
2018	$22,300	$22,300	$8,728	$0	$0
2019	$22,300	$22,300	$8,728	$0	$0
2020	$22,300	$22,300	$8,728	$0	$0
2021	$22,300	$22,300	$0	$0	$0
2022	$22,300	$22,300	$0	$0	$0
2023	$22,300	$22,300	$0	$0	$0
2024	$22,300	$22,300	$0	$0	$0
2025+	$22,300	$22,300	$0	$0	$21,872

7.3.3 Behavioral Parameters

A key feature of the EIM is that it is a behavioral model in that it incorporates economic theory related to producer and consumer behavior to estimate changes in market conditions. As explained in 7.2.1, a behavioral model allows us to examine how manufacturers of affected goods make out adjustments in response to higher production costs due to complying with the control program, and how consumers can be expected to change their consumption choices in response to higher prices resulting from producers passing along at least some part of the compliance costs. The result of these market interactions determines both the new market equilibrium price and quantity and the portion of the compliance costs that will be born by producers and consumers. Thus, the price elasticity of supply and demand are important parameters in behavioral models such as the EIM because they represent how much production and consumption can be expected to change as a result of a price increase.

Table 7-27 and Table 7-28 provide a summary of the demand and supply elasticities used to estimate the economic impact of the proposed standards. Elasticities from peer-reviewed literature were used when possible. Otherwise, the elasticities were estimated using accepted empirical methods (i.e. econometrically; see Appendix 7F) or are derived internally by the EIM. It should be noted that the elasticities in these tables reflect intermediate run behavioral changes. In the long run, supply and demand are expected to be more elastic since more changes can be made to production processes.

7.3.3.1 Demand Elasticities

The EIM requires demand elasticities for the rail and marine transportation markets and the recreational and fishing vessel markets. The demand elasticities for the locomotive, commercial vessels, and marine diesel engine markets are derived in the model. This is another behavioral feature of the model that allows linkages between the different components of the model.

The elasticity for rail transportation services demand is from the peer-reviewed literature and is inelastic (-0.5).[17] This means that the quantity demanded is not expected to be sensitive to price. This is reasonable because, as described above, users of these transportation services typically chose them because they are the best solution for transporting their goods. The decision to choose rail transportation services is a function of many things and the price may not be the most important factor.

We were unable to find the demand elasticity for the marine transportation sector in the peer-reviewed literature. Due to difficulties in gathering the appropriate data to estimate this elasticity, we decided instead to use the same demand elasticity as the rail transportation services market. This is reasonable because a significant portion of the marine transportation sector is engaged in the same basic activity, although with different geographic constraints. Cargo, ferries, supply/crew and tow/tug/pushboats are engaged in transporting materials and people, and the demand for those services is likely to be inelastic because the users have few, if any, alternatives.

For the recreational vessel market, we used a price elasticity of demand that was estimated in 1987 for the National Marine Manufacturers Association.[18] At -1.4, this demand elasticity is elastic, meaning that consumers are expected to be sensitive to a change in price. This is reasonable because recreational marine vessels are a discretionary purchase and consumers have other recreational alternatives.

There were no previously estimated demand elasticities available for the fishing vessel market. Because the demand elasticity for commercial vessels is intenally derived in the EIM, it was not possible to use the commercial vessel market as a proxy. Therefore, we used the estimated demand elasticity for recreationals vessel to approximate the demand elasticity for fishing vessels. The results would be a conservative case, as we would not expect the fishing vessel market to be so elastic since the vessel is an important input to fishing production.

7.3.3.2 Supply Elasticities

Unlike the demand elasticities, it is necessary to estimate a supply elasticity for each of the affected markets.

For the rail transportation service market we use the supply elasticity from our previous economic impact analysis for the Clean Air Nonroad Diesel (Nonroad Tier 4) rule (EPA420-R-04-007). That supply elasticity, from the peer-reviewed literature, is 0.6. This supply elasticity is in elastic, meaning that rail service providers are expected to be insensitive to a price change.

For the line-haul locomotives, we used a calibration method approach to estimate the supply elasticity (see Appendix 7F). At 2.7, this elasticity is elastic, meaning that producers are expected to be sensitive to changes in price. The EIM uses the same supply elasticity for switcher/passenger locomotives. This approach was taken because the market for switchers is currently not very developed. Even if data were available to estimate this supply elasticity, the switcher/passenger locomotive market is expected to change (see Chapter 1 and the discussion earlier in this chapter). Because it is not possible to know how this market will develop, we determined that our best estimate would be the line haul supply elasticity.

We were unable to find published supply elasticity estimates for marine transportation services and therefore the EIM uses the same supply elasticity as for rail transportation services. Again, this is reasonable because the marine transportation service sector provides a similar service, although with different geographic constraints.

For commercial marine vessels, we use the same approach as for line haul locomotives and used the calibration method to estimate the supply elasticity. At 2.3, this elasticity is elastic, meaning that producers are expected to be sensitive to changes in price.

For recreational marine vessels, we used the supply elasticity we estimated in our 2002 recreational vehicle rule.[19] At 1.6, this supply elasticity is elastic, meaning that producers are sensitive to changes in price. They are less sensitive to price changes than commercial vessel manufacturers, however. This is reasonable since recreational vessels are typically serially produced with no specific buyer in mind, using fiberglass molds. Therefore a price increase may have to be higher before affecting production. Also, to some extent, these vessels are more “portable” and can be inventoried, although model year and design may limit the ability of manufacturers to inventory large numbers of these vessels.

There are no prior estimates of the supply elasticity of fishing vessels. The EIM uses the same supply elasticity as recreational vessels. This is reasonable because fishing vessels often have many of the same characteristics as recreational vessels (high-speed planning vessels with fiberglass hulls) and so their production techniques would be similar. At the high end of the market, however, this market may behave more like the commercial vessel market.

The supply elasticity for marine diesel engines is taken from our 2004 Clean Air Nonroad Diesel rule.[20] This is reasonable because the vast majority of marine diesel engines affected by this rule are derived from land-based marine or highway diesel engines. At 3.8, this supply elasticity is elastic, meaning that engine producers are expected to be sensitive to price increases.

Because the demand and supply elasticity estimates are key inputs to the model, a sensitivity analysis was performed to consider the uncertainty that is associated with the estimation process. The results are presented in Appendix 7H.

Table 7-27. Market Demand Elasticities Used in EIM

Market	Estimate	Source	Method	Data Source
Rail				
Rail Transp. Svcs	-0.5	Literature Estimate	Literature Review	Boyer, K.D. 1997. *Principles of Transportation Economics*. Reading, MA: Addison-Wesley.
Locomotives	Derived			
Marine				
Marine Transp. Svcs	-0.5	Literature Estimate	Assumed value	Uses the same elasticity as the locomotive transportation services sector.
Vessels—Commercial	Derived			
Vessels—Fishing	-1.4	Econometric Estimate	Assumed value	Uses the same elasticity as the recreation vessels sector.
Vessels—Recreational	-1.4	Econometric Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2002. *Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines*. EPA420-R-02-022. Available at <http://www.epa.gov/otaq/regs/nonroad/2002/r02022.pdf>.
Engines	Derived			

Table 7-28. Supply Elasticities Used in EIM

Market	Estimate	Source	Method	Input Data Source
Rail				
Rail Transp. Svcs	0.6	Literature Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Available at <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>.

Locomotives	2.7	EPA Estimate	Calibration Method	U.S. Bureau of the Census. 2004a. "Railroad Rolling Stock Manufacturing: 2002." *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336510 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. "Statistics for Industry Groups and Industries: 2004." *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Marine				
Marine Transp. Svcs	0.6		Assumed value	Uses the same elasticity as the rail transportation services sector.
Vessels—Commercial	2.3	EPA Estimate	Calibration Method	U.S. Bureau of the Census. 2004a. "Railroad Rolling Stock Manufacturing: 2002." *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336611 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. "Statistics for Industry Groups and Industries: 2004." *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Vessels—Fishing	1.6	Assumed value	Assumed value	Uses the same elasticity as the recreation vessels sector.
Vessels—Recreational	1.6	Econometric Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2002. *Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines*. EPA420-R-02-022. Available at <http://www.epa.gov/otaq/regs/nonroad/2002/r02022.pdf>.
Engines	3.8	Econometric Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Available at <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>.

7.3.4 Economic Impact Model Structure

7.3.4.1 Estimating With-Regulation Equilibrium Conditions

The economic impact analysis is conducted using the data and the supply and demand framework described above. The price and quantity data, along with the supply and demand elasticities, are used to identify the market supply and demand curves. The regulatory costs are then used to shift the supply curve, and the resulting new equilibrium determines the market impacts and distribution of social impacts.

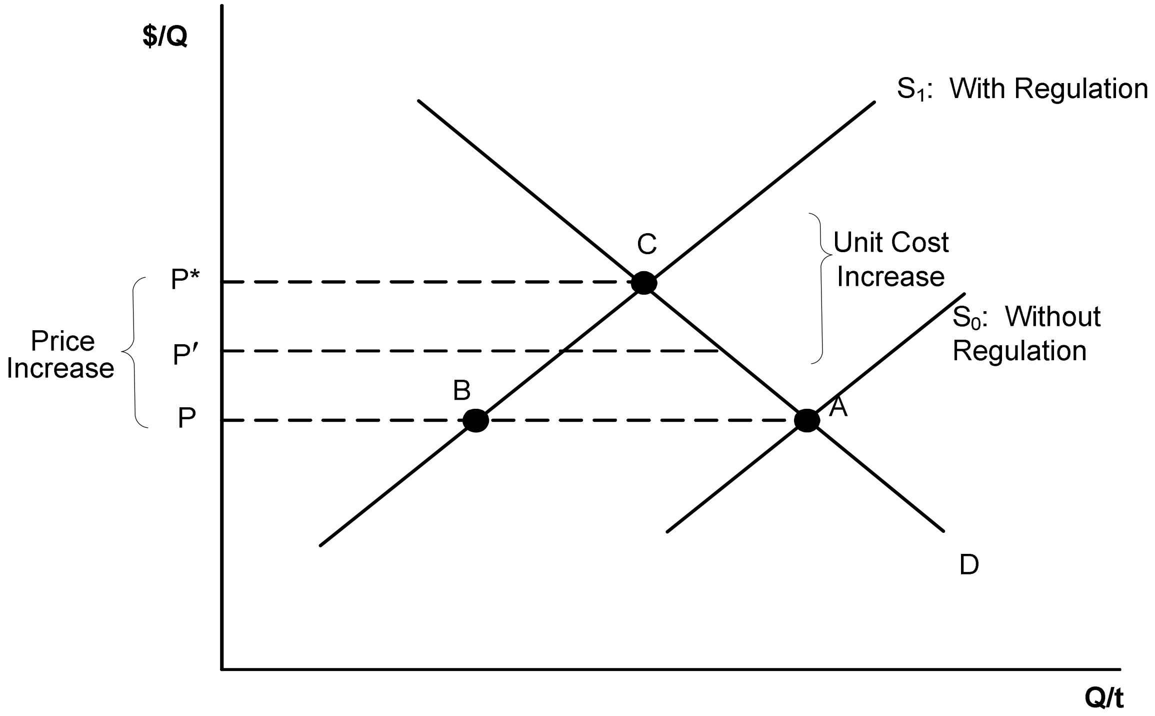
Figure 7-10 illustrates the economic impact modeling structure. Point A represents the initial baseline equilibrium price and quantity (corresponding to the prices and quantities presented in section 7.3.1). The slope of the supply and demand curves passing through the baseline point A are determined by applying the appropriate supply and demand elasticities presented in section 7.3.2.6. These slopes reflect the responsiveness of producers and consumers when prices change and determine how much of the compliance costs producers are able to pass along to consumers in the with-regulation equilibrium.

The compliance costs associated with the regulation (presented in Section 7.3.2) enter the model expressed as per-unit costs and result in an upward shift in the supply curve from S_0 to S_1 in Figure 7-10. Note that the demand curve does not shift because consumer preferences and income are not affected by the regulation (see Section 7.3.2.1)

With the addition of the compliance costs, if prices were not allowed to adjust demanders would still want to consume the quantity at point A, but suppliers would only be willing to supply the quantity at point B (i.e., demand exceeds supply at the baseline price, P). The model then solves for the new equilibrium price (P*) where the quantity demanded equals the quantity supplied. The movement from the baseline equilibrium point A to with-regulation equilibrium point C determines the market impacts (changes in price and quantity) as well as the distribution of social costs. Appendix 7E describes the set of supply and demand equations included in the model. Given the number of equations included in the model, the solution algorithm described below is used to identify the new with-regulation set of equilibrium prices and quantities (Point C).

The analysis illustrated in Figure 7-10 is repeated for each year included in the period of analysis. For future years, a projected time series of prices and quantities are developed and used as the baseline (point A) from which market changes are evaluated. The engineering cost analysis provides quantities for future years using historical annual growth rates. In contrast, there is much more uncertainty surrounding future prices for these markets. As a result, we use a constant 2005 observed prices for the relevant markets during the period of analysis.

Figure 7-10 Estimating With-Regulation Equilibrium



7.3.4.2 Solution Algorithm

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 EIM model uses a similar type of algorithm for determining with-regulation equilibria and the process 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:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s} \right)^z$$

4. Recalculate market supply with new 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.

7.3.5 Estimating Impacts

Using the static partial equilibrium analysis, the EIM model loops through each year calculating new market equilibriums based on the projected baseline economic conditions and compliance cost estimates that shift the supply curves in the model. The model calculates price and quantity changes and uses these measures to estimate the social costs of the rule and partition the impact between producers and consumers. This approach follows the classical treatment of tax burden distribution in the public finance literature.[21]

7.4 Methods for Describing Uncertainty

Every economic impact analysis examining the market and social welfare impacts of a regulatory program is limited to some extent by limitations in model capabilities, deficiencies in the economic literatures with respect to estimated values of key variables necessary to configure the model, and data gaps. In this EIA, there are three main potential sources of uncertainty: (1) uncertainty resulting from the way the EIM is designed, particularly from the use of a partial equilibrium model; (2) uncertainty resulting from the values for key model parameters, particularly the price elasticity of supply and demand; and (3) uncertainty resulting from the values for key model inputs, particularly baseline equilibrium price and quantities. Sources of uncertainty that have a bearing on the results of the EIA for the proposed program are listed and described in more detail in Table 7-29.

The values used for the price elasticities of supply and demand are critical parameters in the EIM. The values of these parameters have an impact on both the estimated change in price and quantity produced expected as a result of compliance with the proposed standards and on how the burden of the social costs will be shared among producer and consumer groups. In selecting the values to use in the EIM it is important that they reflect the behavioral responses of the industries under analysis.

The first source of values for elasticities of supply and demand is the published economic literature. These estimates are peer reviewed and generally constitute reasonable estimates for the industries in question. In this anlaysis, we use a published demand elasticity for recreational marine (Raboy) and for rail trainsportation services (Boyer). On the supply side, we were able to find published elasticities for only the rail transportation sector (Ivaldi and McCollough).

When published elasticities of supply or demand are not available, it is necessary to estimate these values econometrically. In this analysis, we used estimated values for the price elasticity of supply for engines and recreational vessels (see Appendix 7F). These estimates, which were performed for earlier rulemakings (2004 NRT4 rule; 2002 recretional vehicle rule), reflect a production function approach using data at the aggregate industry level. This method was chosen because of limitations with the available data: we were not able to obtain firm-level or plant-level production data for companies that operate in the affected sectors. However, the use of aggregate industry level data may not be appropriate or an accurate way to estimate the price elasticity of supply compared to firm-level or plant-level data. This is because, at the aggregate industry level, the size of the data sample is limited to the time series of the available years and because aggregate industry data may not reveal each individual firm or plant production function (heterogeneity). There may be significant differences among the firms that may be hidden in the aggregate data but that may affect the estimated elasticity. In addition, the use of time series aggregate industry data may introduce time trend effects that are difficult to isolate and control.

To address these concerns, EPA intends to investigate estimates for the price elasticity of supply for the affected industries for which published estimates are not available, using alternative methods and data inputs. This research program will use the cross-sectional data model at either the firm-level or plant level from the U.S. Census Bureau to estimate these elasticities. We plan to use the results of this research provided the results are robust and that they are available in time for the analysis for the final rule.

Table 7-29 Primary Sources of Uncertainty in the Economic Impact Analysis

Source of Uncertainty	Description	Potential Impact
UNCERTAINTIES ASSOCIATED WITH ECONIMIC IMPACT MODEL STRUCTURE		
Partial equilibrium model –	The EIM domain is limited to the economic sectors directly affected by the emission control program; impacts on secondary markets are not accounted for. However, the impacts are not expected to be large as directly affected products and services (locomotives and marine engines and vessels) are production inputs (transportation services) and are not a large share of total production costs for final goods and services, or are final goods for household consumption	Results understate social costs; magnitude of impact is uncertain
National level model	The EIM considers only national-level impacts; regional impacts are not modeled. This is appropriate because locomotive and marine engine and vessel markets are national markets. While there may be some regional differences these are likely to be small due to the competitive nature of the transportation industry.	Impacts uncertain
Supply side assumptions	On the supply side, industries are assumed to be mature and behave linearly within the range of analysis; no substitution between production inputs. This is appropriate because per unit compliance costs are not large enough to prompt a major change in product design or assembly.	Impacts uncertain
Demand side assumptions	On the demand side, end consumer preferences or consumption patterns are assumed to be constant and behave linearly within the range of analysis. This is appropriate because all other factors in the demand function will not be changed by the proposed rule.	Impacts uncertain
Constant price assumption	Prices are assumed to be constant across the period of analysis. This is a reasonable assumption since it is not possible to predict changes in these prices over time (see Appendix 7H)..	Impacts uncertain
Period of analysis	Each period of analysis is assumed to be independent of previous period and producers are assumed to not engage in long-term planning. This means the impacts of multi-tier standards are not smoothed among periods . Because the new engine standards will not go into effect for several years after the program is finalized, producers may in fact take the full program into account in production plans to minimize their costs	Estimated price changes may be too high for early periods, too low for later periods; magnitude of impact is uncertain

Market shock	In the EIM, the market shocked by variable costs only; fixed costs do not disturb the market equilibrium. This is a result of the perfect competition assumption implies market supply curve is the industry average marginal cost curve. This is appropriate because producers in these industries generally plan for R&D and model changes. A sensitivity analysis performed that includes fixed costs in supply shift	Results may overstate distribution of social costs to some producers, understate market impacts; magnitude of impact is uncertain *Sensitivity analysis performed*
UNCERTAINTIES ASSOCIATED WITH PRICE ELASTICITY ESTIMATION		
	Uncertainty resulting from the functional form used in the estimation, the data used (aggregate or firm-level), the time period involved, sample size.	Impacts on distribution of social costs among stakeholders (e.g., higher supply elasticity would result in less social costs for manufacturers and more social costs for consumers) Impacts on market analysis (change in price, change in quantity produced) ; magnitude of impact is uncertain *Sensitivity analysis performed*
UNCERTAINTIES ASSOCIATED WITH DATA INPUTS		
Submarket groupings	Submarket data is assumed to be representative and capture the range of affected equipment. However, the product groupings in NAICS or SIC 4-digit categories may include other engines or equipment that may not have the same production or consumption characteristics; these groupings not behave the same way as the directly-affected industries.	Impacts on social welfare and market analyses uncertain

Baseline equilibrium prices	Estimated baseline equilibrium prices are assumed to be representative and capture the range of affected equipment, and reflect actual transaction prices. However, the actual prices paid by consumers may be different. Also, the mix of products included in price analysis may not be representative of the population.	Impacts on market analysis uncertain
Baseline equilibrium quantities	Estimated baseline equilibrium quantities and future quantities assumed to be representative; these are the same as the cost analysis	Impacts on market analysis uncertain

To explore the effects of key sources of uncertainty, we performed a sensitivity analysis in which we examine the results of using alternative values for the price elasticity of supply and demand, alternative methods to shock to the market equilibrium (fixed and variable costs) and alternative methods to incorporate operational costs (across a larger group of marine vessels). The results of these analyses are contained in Appendix 7H. A summary of the results are presented in Table 7-30.

Table 7-30. Results of Sensitivity Analysis

Parameter	Year	Change in Value	Impact
Price Elasticity of Supply	2020	More elastic	Negligible impact on expected price increase and quantity decrease Higher value associated with increase in social cost burden for users of rail and marine transportation services
	2020	Less elastic	Negligible impact on expected price increase and quantity decrease Lower value associated with increase in social cost burden for suppliers of marine vessels and providers of rail and marine transportation services
Price Elasticity of Demand	2020	More elastic	Negligible impact on expected price increase and quantity decrease Higher value associated with increase in social cost burden for suppliers of marine vessels and providers of rail and marine transportation services
	2020	Less elastic	Negligible impact on expected price increase and quantity decrease Lower value associated with increase in social cost burden for users of rail and marine transportation services
Market Supply Shift	2011, 2015	Include fixed and variable costs	2011: Price increase larger than primary case but decrease in quantity produced remains small, less than 2.5 percent (less than 15 units) for commercial marine engines and vessels and less than 1 percent (about 200 engines and vessels) for recreational marine engines and vessels. Negligible change in locomotive markets. Distribution of social costs shifts from manufacturers to user groups. 2015: Price increase larger than primary case, but decrease in quantity produced remains small, less than 2.0 percent (less than 10 units) for commercial marine engines and vessels and less than 0.1 percent (less than 15 engines and vessels) for recreational marine engines and vessels. Negligible change in locomotive markets. Distribution of social costs shifts from manufacturers to user groups.
Operating Costs	2020	Alternate distribution	Negligible change in results; increase in social cost burden for recreational and fishing vessel consumers

Appendix 7A: Impacts on Marine Engine Markets

This appendix provides the time series of impacts from 2007 through 2040 for selected auxiliary and propulsion marine engines markets. Table 7A-1 through Table 7A-8 provide the time series of impacts and include the following:

- average engineering costs (variable) per engine
- absolute change in the market price ($)
- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs (variable and fixed) associated with each engine market
- changes in engine manufacturer surplus

All prices, costs, and surplus changes are presented in 2005 dollars, and real engine or equipment prices are assumed to be constant during the period of analysis. Net present values for 2006 were calculated using social discount rates of 3% and 7% over the 2007 and 2040 time period.

Results are presented for only those markets that are expected to incur direct variable costs under Tier 3 or Tier 4 standards. This means that results are not presented for marine engine markets less than 800 hp or for recreational propulsion engine markets.[16] For these engine markets, the results are expected to be negligible and any change in price or quantity would be incidental to the changes in the larger engine markets. It should also be noted that all engine markets would incur fixed costs. However, as explained in 7.2.3.4, fixed costs are not included in the EIM. The sensitivity analysis in Appendix 7H includes a case that applies both fixed and variable costs to the relevant markets.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

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[16] This version of the EIA is based on an earlier version of the marine emission control program that did not apply Tier 4 standards to any recreational marine diesel engines.

Table 7A-1. Impact on C1 Commercial Auxiliary Engine Market: 800–2000 hp (Average Price per Engine = $77,500)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers'' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.3	-$0.3
2008	$0	$0	0.0%	0.0%	$0.3	-$0.3
2009	$0	$0	0.0%	0.0%	$0.3	-$0.3
2010	$0	$0	0.0%	0.0%	$0.3	-$0.3
2011	$0	$0	0.0%	0.0%	$3.9	-$3.9
2012	$0	$0	0.0%	0.0%	$3.5	-$3.5
2013	$0	$0	0.0%	0.0%	$3.5	-$3.5
2014	$0	$0	0.0%	0.0%	$3.5	-$3.5
2015	$0	$0	0.0%	0.0%	$4.6	-$4.6
2016	$15,319	$14,958	19.3%	-1.8%	$2.5	-$0.1
2017	$15,319	$14,958	19.3%	-1.8%	$2.5	-$0.1
2018	$11,763	$11,478	14.8%	-1.4%	$1.9	Loss less than $0.1
2019	$11,763	$11,478	14.8%	-1.4%	$1.9	Loss less than $0.1
2020	$11,763	$11,478	14.8%	-1.4%	$2.0	Loss less than $0.1
2021	$11,763	$11,477	14.8%	-1.4%	$2.0	Loss less than $0.1
2022	$11,763	$11,477	14.8%	-1.4%	$2.0	Loss less than $0.1
2023	$11,763	$11,476	14.8%	-1.4%	$2.0	Loss less than $0.1
2024	$11,763	$11,476	14.8%	-1.4%	$2.0	Loss less than $0.1
2025	$11,763	$11,475	14.8%	-1.4%	$2.1	Loss less than $0.1
2026	$11,763	$11,475	14.8%	-1.4%	$2.1	-$0.1
2027	$11,763	$11,474	14.8%	-1.4%	$2.1	-$0.1
2028	$11,763	$11,474	14.8%	-1.4%	$2.1	-$0.1
2029	$11,763	$11,473	14.8%	-1.4%	$2.1	-$0.1
2030	$11,763	$11,473	14.8%	-1.4%	$2.1	-$0.1
2031	$11,763	$11,473	14.8%	-1.4%	$2.2	-$0.1
2032	$11,763	$11,473	14.8%	-1.4%	$2.2	-$0.1
2033	$11,763	$11,473	14.8%	-1.4%	$2.2	-$0.1
2034	$11,763	$11,472	14.8%	-1.4%	$2.2	-$0.1
2035	$11,763	$11,472	14.8%	-1.4%	$2.2	-$0.1
2036	$11,763	$11,472	14.8%	-1.4%	$2.3	-$0.1
2037	$11,763	$11,472	14.8%	-1.4%	$2.3	-$0.1
2038	$11,763	$11,472	14.8%	-1.4%	$2.3	-$0.1
2039	$11,763	$11,471	14.8%	-1.4%	$2.3	-$0.1
2040	$11,763	$11,472	14.8%	-1.4%	$2.3	-$0.1
NPV at 3%					$44.0	-$16.9
NPV at 7%					$24.8	-$12.4

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-2 Impact on C1 Commercial Auxiliary Engine Market: >2000 hp (Average Price per Engine = $150,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers'' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	$0.4	–$0.4
2012	$0	$0	0.0%	0.0%	$0.3	–$0.3
2013	$0	$0	0.0%	0.0%	$0.3	–$0.3
2014	$0	–$3	0.0%	0.0%	$0.3	–$0.3
2015	$0	–$6	0.0%	0.0%	$0.4	–$0.4
2016	$26,294	$26,194	17.4%	–0.5%	$0.4	Loss less than $0.1
2017	$26,295	$26,185	17.4%	–0.5%	$0.4	Loss less than $0.1
2018	$20,115	$20,012	13.3%	–0.5%	$0.3	Loss less than $0.1
2019	$20,114	$19,999	13.3%	–0.6%	$0.3	Loss less than $0.1
2020	$20,118	$19,991	13.2%	–0.6%	$0.3	Loss less than $0.1
2021	$20,113	$19,975	13.2%	–0.7%	$0.3	Loss less than $0.1
2022	$20,114	$19,964	13.2%	–0.7%	$0.3	Loss less than $0.1
2023	$20,113	$19,952	13.2%	–0.8%	$0.3	Loss less than $0.1
2024	$20,117	$19,945	13.2%	–0.8%	$0.3	Loss less than $0.1
2025	$20,113	$19,931	13.2%	–0.9%	$0.3	Loss less than $0.1
2026	$20,113	$19,921	13.2%	–0.9%	$0.3	Loss less than $0.1
2027	$20,118	$19,917	13.2%	–1.0%	$0.3	Loss less than $0.1
2028	$20,116	$19,905	13.1%	–1.0%	$0.3	Loss less than $0.1
2029	$20,117	$19,898	13.1%	–1.1%	$0.3	Loss less than $0.1
2030	$20,117	$19,891	13.1%	–1.1%	$0.3	Loss less than $0.1
2031	$20,116	$19,883	13.1%	–1.1%	$0.3	Loss less than $0.1
2032	$20,113	$19,874	13.1%	–1.2%	$0.3	Loss less than $0.1
2033	$20,114	$19,870	13.1%	–1.2%	$0.3	Loss less than $0.1
2034	$20,114	$19,865	13.1%	–1.2%	$0.3	Loss less than $0.1
2035	$20,117	$19,865	13.1%	–1.2%	$0.4	Loss less than $0.1
2036	$20,114	$19,857	13.1%	–1.3%	$0.4	Loss less than $0.1
2037	$20,114	$19,854	13.1%	–1.3%	$0.4	Loss less than $0.1
2038	$20,113	$19,850	13.1%	–1.3%	$0.4	Loss less than $0.1
2039	$20,116	$19,851	13.1%	–1.3%	$0.4	Loss less than $0.1
2040	$20,117	$19,850	13.1%	–1.3%	$0.4	Loss less than $0.1
NPV at 3%					$5.8	–$1.5
NPV at 7%					$3.1	–$1.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-3 Impact on C2 Commercial Auxiliary Engine Market: 800–2,000 hp (Average Price per Engine = $115,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers'' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.9	-$0.9
2008	$0	$0	0.0%	0.0%	$0.9	-$0.9
2009	$0	$0	0.0%	0.0%	$0.9	-$0.9
2010	$0	$0	0.0%	0.0%	$0.9	-$0.9
2011	$0	$0	0.0%	0.0%	$5.7	-$5.7
2012	$0	$0	0.0%	0.0%	$4.2	-$4.2
2013	$0	$0	0.0%	0.0%	$4.2	-$4.2
2014	$0	-$1	0.0%	0.0%	$4.2	-$4.2
2015	$0	-$2	0.0%	0.0%	$6.1	-$6.1
2016	$39,059	$38,759	33.7%	-1.0%	$2.5	Loss less than $0.1
2017	$39,058	$38,755	33.7%	-1.0%	$2.5	Loss less than $0.1
2018	$29,827	$29,587	25.7%	-0.8%	$1.9	Loss less than $0.1
2019	$29,827	$29,581	25.7%	-0.8%	$1.9	Loss less than $0.1
2020	$29,827	$29,577	25.7%	-0.8%	$2.0	Loss less than $0.1
2021	$29,827	$29,573	25.7%	-0.8%	$2.0	Loss less than $0.1
2022	$29,827	$29,568	25.7%	-0.9%	$2.0	Loss less than $0.1
2023	$29,827	$29,564	25.7%	-0.9%	$2.0	Loss less than $0.1
2024	$29,826	$29,560	25.7%	-0.9%	$2.0	Loss less than $0.1
2025	$29,826	$29,555	25.7%	-0.9%	$2.1	Loss less than $0.1
2026	$29,827	$29,552	25.7%	-0.9%	$2.1	Loss less than $0.1
2027	$29,827	$29,546	25.7%	-0.9%	$2.1	Loss less than $0.1
2028	$29,827	$29,543	25.7%	-0.9%	$2.1	Loss less than $0.1
2029	$29,826	$29,539	25.7%	-1.0%	$2.1	Loss less than $0.1
2030	$29,827	$29,537	25.7%	-1.0%	$2.1	Loss less than $0.1
2031	$29,827	$29,534	25.7%	-1.0%	$2.2	Loss less than $0.1
2032	$29,827	$29,532	25.7%	-1.0%	$2.2	Loss less than $0.1
2033	$29,827	$29,530	25.7%	-1.0%	$2.2	Loss less than $0.1
2034	$29,827	$29,528	25.7%	-1.0%	$2.2	Loss less than $0.1
2035	$29,826	$29,526	25.7%	-1.0%	$2.2	Loss less than $0.1
2036	$29,826	$29,525	25.7%	-1.0%	$2.3	Loss less than $0.1
2037	$29,827	$29,524	25.7%	-1.0%	$2.3	Loss less than $0.1
2038	$29,827	$29,523	25.7%	-1.0%	$2.3	Loss less than $0.1
2039	$29,827	$29,523	25.7%	-1.0%	$2.3	Loss less than $0.1
2040	$29,827	$29,522	25.7%	-1.0%	$2.3	Loss less than $0.1
NPV at 3%					$50.3	-$22.7
NPV at 7%					$29.7	-$17.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-4 Impact on C2 Commercial Auxiliary Engine Market: >2,000 hp (Average Price per Engine = $225,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers'' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$1.3	-$1.3
2008	$0	$0	0.0%	0.0%	$1.3	-$1.3
2009	$0	$0	0.0%	0.0%	$1.3	-$1.3
2010	$0	$0	0.0%	0.0%	$1.3	-$1.3
2011	$0	$0	0.0%	0.0%	$8.7	-$8.7
2012	$0	$0	0.0%	0.0%	$6.5	-$6.5
2013	$0	$0	0.0%	0.0%	$6.5	-$6.5
2014	$0	-$2	0.0%	0.0%	$6.5	-$6.5
2015	$0	-$5	0.0%	0.0%	$9.4	-$9.4
2016	$72,301	$71,824	31.9%	-0.8%	$7.0	Loss less than $0.1
2017	$72,301	$71,816	31.9%	-0.8%	$7.1	Loss less than $0.1
2018	$55,120	$54,733	24.3%	-0.7%	$5.5	Loss less than $0.1
2019	$55,121	$54,724	24.3%	-0.7%	$5.5	Loss less than $0.1
2020	$55,121	$54,715	24.3%	-0.7%	$5.6	Loss less than $0.1
2021	$55,121	$54,706	24.3%	-0.7%	$5.6	Loss less than $0.1
2022	$55,121	$54,697	24.3%	-0.7%	$5.7	Loss less than $0.1
2023	$55,120	$54,688	24.3%	-0.7%	$5.7	Loss less than $0.1
2024	$55,120	$54,680	24.3%	-0.7%	$5.8	Loss less than $0.1
2025	$55,121	$54,672	24.3%	-0.8%	$5.8	Loss less than $0.1
2026	$55,121	$54,664	24.3%	-0.8%	$5.9	Loss less than $0.1
2027	$55,121	$54,656	24.3%	-0.8%	$5.9	Loss less than $0.1
2028	$55,121	$54,649	24.3%	-0.8%	$6.0	-$0.1
2029	$55,120	$54,642	24.3%	-0.8%	$6.0	-$0.1
2030	$55,121	$54,637	24.3%	-0.8%	$6.1	-$0.1
2031	$55,121	$54,632	24.3%	-0.8%	$6.1	-$0.1
2032	$55,120	$54,627	24.3%	-0.8%	$6.2	-$0.1
2033	$55,120	$54,623	24.3%	-0.8%	$6.3	-$0.1
2034	$55,121	$54,620	24.3%	-0.8%	$6.3	-$0.1
2035	$55,121	$54,616	24.3%	-0.9%	$6.4	-$0.1
2036	$55,120	$54,613	24.3%	-0.9%	$6.4	-$0.1
2037	$55,121	$54,610	24.3%	-0.9%	$6.5	-$0.1
2038	$55,121	$54,608	24.3%	-0.9%	$6.5	-$0.1
2039	$55,121	$54,607	24.3%	-0.9%	$6.6	-$0.1
2040	$55,121	$54,605	24.3%	-0.9%	$6.7	-$0.1
NPV at 3%					$113.5	-$35.1
NPV at 7%					$62.2	-$26.4

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-5 Impact on C1 Commercial Propulsion Engine Market: 800–2,000 hp (Average Price per Engine = $155,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers'' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$1.0	-$1.0
2008	$0	$0	0.0%	0.0%	$1.0	-$1.0
2009	$0	$0	0.0%	0.0%	$1.0	-$1.0
2010	$0	$0	0.0%	0.0%	$1.0	-$1.0
2011	$0	$0	0.0%	0.0%	$13.1	-$13.1
2012	$0	$0	0.0%	0.0%	$11.7	-$11.7
2013	$0	$0	0.0%	0.0%	$11.7	-$11.7
2014	$0	$0	0.0%	0.0%	$11.7	-$11.7
2015	$0	-$1	0.0%	0.0%	$15.3	-$15.3
2016	$15,319	$14,597	9.4%	-1.8%	$8.2	-$0.4
2017	$15,319	$14,596	9.4%	-1.8%	$8.3	-$0.4
2018	$11,763	$11,194	7.2%	-1.4%	$6.4	-$0.3
2019	$11,763	$11,193	7.2%	-1.4%	$6.5	-$0.3
2020	$11,763	$11,192	7.2%	-1.4%	$6.5	-$0.3
2021	$11,763	$11,191	7.2%	-1.4%	$6.6	-$0.3
2022	$11,763	$11,190	7.2%	-1.4%	$6.6	-$0.3
2023	$11,763	$11,189	7.2%	-1.4%	$6.7	-$0.3
2024	$11,763	$11,188	7.2%	-1.4%	$6.8	-$0.3
2025	$11,763	$11,187	7.2%	-1.4%	$6.8	-$0.3
2026	$11,763	$11,186	7.2%	-1.4%	$6.9	-$0.3
2027	$11,763	$11,185	7.2%	-1.4%	$6.9	-$0.3
2028	$11,763	$11,185	7.2%	-1.4%	$7.0	-$0.3
2029	$11,763	$11,184	7.2%	-1.4%	$7.1	-$0.3
2030	$11,763	$11,183	7.2%	-1.4%	$7.1	-$0.3
2031	$11,763	$11,183	7.2%	-1.4%	$7.2	-$0.4
2032	$11,763	$11,182	7.2%	-1.4%	$7.3	-$0.4
2033	$11,763	$11,182	7.2%	-1.4%	$7.3	-$0.4
2034	$11,763	$11,181	7.2%	-1.4%	$7.4	-$0.4
2035	$11,763	$11,181	7.2%	-1.4%	$7.5	-$0.4
2036	$11,763	$11,181	7.2%	-1.4%	$7.5	-$0.4
2037	$11,763	$11,180	7.2%	-1.4%	$7.6	-$0.4
2038	$11,763	$11,180	7.2%	-1.4%	$7.7	-$0.4
2039	$11,763	$11,180	7.2%	-1.4%	$7.7	-$0.4
2040	$11,763	$11,180	7.2%	-1.4%	$7.8	-$0.4
NPV at 3%					$146.3	-$58.3
NPV at 7%					$82.3	-$42.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-6 Impact on C1 Commercial Propulsion Engine Market: >2,000 hp (Average Price per Engine = $300,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers'' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.4	-$0.4
2008	$0	$0	0.0%	0.0%	$0.4	-$0.4
2009	$0	$0	0.0%	0.0%	$0.4	-$0.4
2010	$0	$0	0.0%	0.0%	$0.4	-$0.4
2011	$0	$0	0.0%	0.0%	$5.4	-$5.4
2012	$0	$0	0.0%	0.0%	$4.9	-$4.9
2013	$0	$0	0.0%	0.0%	$4.9	-$4.9
2014	$0	$0	0.0%	0.0%	$4.9	-$4.9
2015	$0	-$1	0.0%	0.0%	$6.4	-$6.4
2016	$26,296	$25,082	8.4%	-1.5%	$5.8	-$0.3
2017	$26,296	$25,081	8.4%	-1.5%	$5.9	-$0.3
2018	$20,115	$19,157	6.4%	-1.2%	$4.5	-$0.2
2019	$20,115	$19,155	6.4%	-1.2%	$4.6	-$0.2
2020	$20,116	$19,154	6.4%	-1.2%	$4.6	-$0.2
2021	$20,116	$19,152	6.4%	-1.2%	$4.7	-$0.2
2022	$20,115	$19,150	6.4%	-1.2%	$4.7	-$0.2
2023	$20,116	$19,146	6.4%	-1.2%	$4.8	-$0.2
2024	$20,115	$19,144	6.4%	-1.2%	$4.8	-$0.2
2025	$20,115	$19,143	6.4%	-1.2%	$4.8	-$0.2
2026	$20,116	$19,142	6.4%	-1.2%	$4.9	-$0.2
2027	$20,116	$19,141	6.4%	-1.2%	$4.9	-$0.2
2028	$20,115	$19,140	6.4%	-1.2%	$5.0	-$0.2
2029	$20,116	$19,136	6.4%	-1.2%	$5.0	-$0.2
2030	$20,115	$19,136	6.4%	-1.2%	$5.1	-$0.2
2031	$20,115	$19,135	6.4%	-1.2%	$5.1	-$0.2
2032	$20,116	$19,136	6.4%	-1.2%	$5.1	-$0.2
2033	$20,115	$19,133	6.4%	-1.2%	$5.2	-$0.3
2034	$20,116	$19,133	6.4%	-1.2%	$5.3	-$0.3
2035	$20,116	$19,133	6.4%	-1.2%	$5.3	-$0.3
2036	$20,115	$19,131	6.4%	-1.2%	$5.4	-$0.3
2037	$20,116	$19,131	6.4%	-1.2%	$5.4	-$0.3
2038	$20,115	$19,129	6.4%	-1.2%	$5.5	-$0.3
2039	$20,115	$19,130	6.4%	-1.2%	$5.5	-$0.3
2040	$20,116	$19,131	6.4%	-1.2%	$5.5	-$0.3
NPV at 3%					$88.0	-$25.4
NPV at 7%					$46.6	-$18.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-7 Impact on C2 Commercial Propulsion Engine Market: 800–2,000 hp (Average Price per Engine = $232,500)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.1	-$0.1
2008	$0	$0	0.0%	0.0%	$0.1	-$0.1
2009	$0	$0	0.0%	0.0%	$0.1	-$0.1
2010	$0	$0	0.0%	0.0%	$0.1	-$0.1
2011	$0	$0	0.0%	0.0%	$0.7	-$0.7
2012	$0	$0	0.0%	0.0%	$0.5	-$0.5
2013	$0	$0	0.0%	0.0%	$0.5	-$0.5
2014	$0	-$2	0.0%	0.0%	$0.5	-$0.5
2015	$0	-$5	0.0%	0.0%	$0.7	-$0.7
2016	$39,057	$38,458	16.7%	-1.0%	$0.3	Loss less than $0.1
2017	$39,057	$38,451	16.7%	-1.0%	$0.3	Loss less than $0.1
2018	$29,829	$29,347	12.8%	-0.8%	$0.2	Loss less than $0.1
2019	$29,829	$29,338	12.8%	-0.8%	$0.2	Loss less than $0.1
2020	$29,829	$29,329	12.8%	-0.8%	$0.2	Loss less than $0.1
2021	$29,829	$29,320	12.7%	-0.8%	$0.2	Loss less than $0.1
2022	$29,829	$29,312	12.7%	-0.9%	$0.2	Loss less than $0.1
2023	$29,829	$29,303	12.7%	-0.9%	$0.2	Loss less than $0.1
2024	$29,829	$29,295	12.7%	-0.9%	$0.2	Loss less than $0.1
2025	$29,829	$29,287	12.7%	-0.9%	$0.2	Loss less than $0.1
2026	$29,829	$29,279	12.7%	-0.9%	$0.2	Loss less than $0.1
2027	$29,825	$29,263	12.7%	-0.9%	$0.2	Loss less than $0.1
2028	$29,825	$29,256	12.7%	-0.9%	$0.2	Loss less than $0.1
2029	$29,825	$29,250	12.7%	-1.0%	$0.2	Loss less than $0.1
2030	$29,825	$29,244	12.7%	-1.0%	$0.2	Loss less than $0.1
2031	$29,825	$29,239	12.7%	-1.0%	$0.2	Loss less than $0.1
2032	$29,825	$29,235	12.7%	-1.0%	$0.2	Loss less than $0.1
2033	$29,825	$29,231	12.7%	-1.0%	$0.2	Loss less than $0.1
2034	$29,825	$29,228	12.7%	-1.0%	$0.2	Loss less than $0.1
2035	$29,825	$29,225	12.7%	-1.0%	$0.2	Loss less than $0.1
2036	$29,825	$29,222	12.7%	-1.0%	$0.2	Loss less than $0.1
2037	$29,825	$29,219	12.7%	-1.0%	$0.2	Loss less than $0.1
2038	$29,825	$29,217	12.7%	-1.0%	$0.2	Loss less than $0.1
2039	$29,825	$29,216	12.7%	-1.0%	$0.2	Loss less than $0.1
2040	$29,825	$29,215	12.7%	-1.0%	$0.2	Loss less than $0.1
NPV at 3%					$5.5	-$2.6
NPV at 7%					$3.3	-$1.9

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7A-8 Impact on C2 Commercial Propulsion Engine Market: >2,000 hp (Average Price per Engine = $450,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Engine Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$1.9	-$1.9
2008	$0	$0	0.0%	0.0%	$1.9	-$1.9
2009	$0	$0	0.0%	0.0%	$1.9	-$1.9
2010	$0	$0	0.0%	0.0%	$1.9	-$1.9
2011	$0	$0	0.0%	0.0%	$12.7	-$12.7
2012	$0	$0	0.0%	0.0%	$9.5	-$9.5
2013	$0	$0	0.0%	0.0%	$9.5	-$9.5
2014	$0	-$5	0.0%	0.0%	$9.5	-$9.5
2015	$0	-$9	0.0%	0.0%	$13.7	-$13.7
2016	$72,301	$71,346	15.9%	-0.8%	$10.2	-$0.1
2017	$72,301	$71,332	15.9%	-0.8%	$10.3	-$0.1
2018	$55,121	$54,346	12.1%	-0.7%	$8.0	-$0.1
2019	$55,121	$54,327	12.1%	-0.7%	$8.0	-$0.1
2020	$55,121	$54,309	12.1%	-0.7%	$8.1	-$0.1
2021	$55,121	$54,291	12.1%	-0.7%	$8.2	-$0.1
2022	$55,121	$54,273	12.1%	-0.7%	$8.2	-$0.1
2023	$55,121	$54,256	12.1%	-0.7%	$8.3	-$0.1
2024	$55,121	$54,239	12.1%	-0.7%	$8.4	-$0.1
2025	$55,120	$54,223	12.0%	-0.8%	$8.5	-$0.1
2026	$55,120	$54,207	12.0%	-0.8%	$8.5	-$0.1
2027	$55,120	$54,192	12.0%	-0.8%	$8.6	-$0.1
2028	$55,121	$54,178	12.0%	-0.8%	$8.7	-$0.1
2029	$55,121	$54,165	12.0%	-0.8%	$8.8	-$0.2
2030	$55,120	$54,153	12.0%	-0.8%	$8.9	-$0.2
2031	$55,120	$54,143	12.0%	-0.8%	$8.9	-$0.2
2032	$55,121	$54,134	12.0%	-0.8%	$9.0	-$0.2
2033	$55,121	$54,126	12.0%	-0.8%	$9.1	-$0.2
2034	$55,120	$54,118	12.0%	-0.8%	$9.2	-$0.2
2035	$55,120	$54,111	12.0%	-0.9%	$9.3	-$0.2
2036	$55,121	$54,105	12.0%	-0.9%	$9.3	-$0.2
2037	$55,121	$54,100	12.0%	-0.9%	$9.4	-$0.2
2038	$55,120	$54,095	12.0%	-0.9%	$9.5	-$0.2
2039	$55,121	$54,093	12.0%	-0.9%	$9.6	-$0.2
2040	$55,120	$54,090	12.0%	-0.9%	$9.7	-$0.2
NPV at 3%					$165.0	-$52.0
NPV at 7%					$90.4	-$38.9

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7B: Impacts on the Equipment Markets

This appendix provides the time series of impacts from 2007 through 2040 for selected equipment markets (vessels and locomotives). Results are presented for 26 separate equipment markets: 2 locomotive markets (line-haul and switchers) and 24 vessel markets. Table 7B-1 through Table 7B-26 provide the time series of impacts and include the following:

- average engineering costs (variable) per equipment
- absolute change in the market price ($)
- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs (variable and fixed) associated with each engine market
- changes in equipment manufacturer surplus (selected commercial vessel and locomotive markets)
- changes in consumer surplus (recreational and fishing markets only)
- changes in total surplus (recreational and fishing markets only)

All prices, costs, and surplus changes are presented in 2005 dollars, and real equipment prices are assumed to be constant during the period of analysis. Net present values for 2006 were calculated using social discount rates of 3% and 7% over the 2007 and 2040 time period.

Results are presented for only those markets that are expected to incur direct variable costs under Tier 3 or Tier 4 standards. This means that results are not presented for marine vessel markets for vessels that have propulsion engines less than 800 hp or for recreational vessel markets.[17] For these vessel markets, the results are expected to be negligible and any change in price or quantity would be incidental to the changes in the larger vessel markets. It should also be noted that fixed costs are limited to only the Tier 4 standards. There are no fixed costs associated with the Tier 3 standards because Tier 3 engines are expected to have the same engine footprint as Tier 2 engines. For Tier 4 vessels, as explained in 7.2.3.4, fixed costs are not included in the EIM. The sensitivity analysis in Appendix 7H includes a case that applies both fixed and variable costs to the relevant markets.

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[17] This version of the EIA is based on an earlier version of the marine emission control program that did not apply Tier 4 standards to any recreational marine diesel engines.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

Table 7B-1. Impact on Locomotive Market: Line-Haul (Average Price per Locomotive = $2,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.6	-$0.6
2008	$0	-$255	0.0%	0.0%	$0.6	-$0.8
2009	$0	-$151	0.0%	0.0%	$0.6	-$0.7
2010	$0	-$239	0.0%	0.0%	$2.3	-$2.5
2011	$0	-$449	0.0%	-0.1%	$3.9	-$4.2
2012	$0	-$357	0.0%	0.0%	$5.1	-$5.4
2013	$0	-$313	0.0%	0.0%	$5.1	-$5.4
2014	$0	-$219	0.0%	0.0%	$7.2	-$7.4
2015	$44,390	$44,041	2.2%	0.0%	$39.7	-$3.7
2016	$44,390	$43,911	2.2%	-0.1%	$43.4	-$5.9
2017	$68,544	$67,982	3.4%	-0.1%	$60.1	-$0.5
2018	$68,544	$67,923	3.4%	-0.1%	$61.3	-$0.6
2019	$60,624	$60,006	3.0%	-0.1%	$55.6	-$0.6
2020	$60,624	$60,050	3.0%	-0.1%	$57.5	-$0.5
2021	$60,624	$59,991	3.0%	-0.1%	$59.3	-$0.6
2022	$60,624	$59,852	3.0%	-0.1%	$61.0	-$0.8
2023	$60,624	$59,626	3.0%	-0.1%	$62.7	-$1.0
2024	$60,624	$59,623	3.0%	-0.1%	$63.5	-$1.0
2025	$60,624	$59,557	3.0%	-0.1%	$65.3	-$1.1
2026	$60,624	$59,561	3.0%	-0.1%	$66.5	-$1.2
2027	$60,624	$59,509	3.0%	-0.2%	$67.8	-$1.2
2028	$60,624	$59,407	3.0%	-0.2%	$68.9	-$1.4
2029	$60,624	$59,359	3.0%	-0.2%	$69.7	-$1.5
2030	$60,624	$59,321	3.0%	-0.2%	$70.2	-$1.5
2031	$60,624	$59,279	3.0%	-0.2%	$71.1	-$1.6
2032	$60,624	$59,253	3.0%	-0.2%	$72.1	-$1.6
2033	$60,624	$59,017	3.0%	-0.2%	$73.3	-$1.9
2034	$60,624	$58,950	2.9%	-0.2%	$74.2	-$2.0
2035	$60,624	$58,891	2.9%	-0.2%	$74.6	-$2.1
2036	$60,624	$58,892	2.9%	-0.2%	$72.5	-$2.1
2037	$60,624	$58,858	2.9%	-0.2%	$71.0	-$2.1
2038	$60,624	$58,827	2.9%	-0.2%	$69.4	-$2.1
2039	$60,624	$58,798	2.9%	-0.2%	$67.4	-$2.0
2040	$60,624	$58,772	2.9%	-0.3%	$65.4	-$2.0
NPV at 3%					$886.5	-$44.5
NPV at 7%					$408.7	-$27.7

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-2. Impact on Locomotive Market: Switchers (Average Price per Locomotive = $1,300,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$2.6	-$2.6
2008	$0	-$166	0.0%	0.0%	$2.6	-$2.6
2009	$0	-$98	0.0%	0.0%	$2.6	-$2.6
2010	$0	-$155	0.0%	0.0%	$4.9	-$5.0
2011	$0	-$292	0.0%	-0.1%	$6.9	-$7.0
2012	$0	-$232	0.0%	0.0%	$7.2	-$7.2
2013	$0	-$203	0.0%	0.0%	$7.2	-$7.3
2014	$0	-$142	0.0%	0.0%	$9.7	-$9.8
2015	$14,353	$14,126	1.1%	0.0%	$9.1	-$4.9
2016	$14,353	$14,042	1.1%	-0.1%	$11.8	-$7.4
2017	$19,230	$18,865	1.5%	-0.1%	$6.4	-$0.1
2018	$19,230	$18,827	1.4%	-0.1%	$6.6	-$0.1
2019	$17,770	$17,368	1.3%	-0.1%	$6.3	-$0.1
2020	$17,770	$17,396	1.3%	-0.1%	$6.6	-$0.1
2021	$17,770	$17,358	1.3%	-0.1%	$6.9	-$0.2
2022	$17,770	$17,268	1.3%	-0.1%	$7.1	-$0.2
2023	$17,770	$17,121	1.3%	-0.1%	$7.1	-$0.3
2024	$17,770	$17,119	1.3%	-0.1%	$7.2	-$0.3
2025	$17,770	$17,076	1.3%	-0.1%	$7.1	-$0.3
2026	$17,770	$17,078	1.3%	-0.1%	$7.0	-$0.3
2027	$17,770	$17,045	1.3%	-0.2%	$6.8	-$0.3
2028	$17,770	$16,978	1.3%	-0.2%	$6.7	-$0.3
2029	$17,770	$16,947	1.3%	-0.2%	$6.6	-$0.3
2030	$17,770	$16,922	1.3%	-0.2%	$6.5	-$0.3
2031	$17,770	$16,895	1.3%	-0.2%	$6.4	-$0.3
2032	$17,770	$16,878	1.3%	-0.2%	$6.4	-$0.3
2033	$17,770	$16,725	1.3%	-0.2%	$5.6	-$0.3
2034	$17,770	$16,681	1.3%	-0.2%	$5.4	-$0.3
2035	$17,770	$16,643	1.3%	-0.2%	$5.2	-$0.3
2036	$17,770	$16,644	1.3%	-0.2%	$4.9	-$0.3
2037	$17,770	$16,622	1.3%	-0.2%	$4.7	-$0.3
2038	$17,770	$16,602	1.3%	-0.2%	$4.5	-$0.3
2039	$17,770	$16,582	1.3%	-0.2%	$4.4	-$0.3
2040	$17,770	$16,566	1.3%	-0.3%	$4.2	-$0.3
NPV at 3%					$128.0	-$48.4
NPV at 7%					$73.6	-$35.8

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-3. Impact on C1 Tow/Tug/Push Vessel Market: 800–2,000 hp (Average Price per Vessel = $1,550,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2014	$0	-$27	0.0%	0.0%	$0.0	Loss less than $0.1
2015	$0	-$55	0.0%	0.0%	$0.9	-$0.9
2016	$2,384	$29,430	1.9%	-0.1%	$0.5	-$0.5
2017	$2,386	$29,346	1.9%	-0.1%	$0.3	-$0.3
2018	$2,385	$22,900	1.5%	-0.1%	$0.2	-$0.2
2019	$2,386	$22,791	1.5%	-0.1%	$0.2	-$0.2
2020	$2,384	$22,682	1.5%	-0.1%	$0.2	-$0.2
2021	$2,385	$22,578	1.5%	-0.1%	$0.2	-$0.2
2022	$2,385	$22,477	1.5%	-0.2%	$0.2	-$0.2
2023	$2,386	$22,377	1.4%	-0.2%	$0.2	-$0.2
2024	$2,386	$22,280	1.4%	-0.2%	$0.2	-$0.2
2025	$2,386	$22,186	1.4%	-0.2%	$0.2	-$0.2
2026	$2,386	$22,094	1.4%	-0.2%	$0.2	-$0.2
2027	$2,386	$22,005	1.4%	-0.2%	$0.1	-$0.1
2028	$2,385	$21,920	1.4%	-0.3%	$0.1	-$0.1
2029	$2,384	$21,843	1.4%	-0.3%	$0.1	-$0.1
2030	$2,386	$21,778	1.4%	-0.3%	$0.1	-$0.1
2031	$2,385	$21,718	1.4%	-0.3%	$0.1	-$0.1
2032	$2,386	$21,668	1.4%	-0.3%	$0.1	-$0.1
2033	$2,385	$21,619	1.4%	-0.3%	$0.1	-$0.1
2034	$2,386	$21,576	1.4%	-0.3%	$0.1	-$0.1
2035	$2,386	$21,537	1.4%	-0.3%	$0.1	-$0.1
2036	$2,384	$21,498	1.4%	-0.3%	$0.1	-$0.1
2037	$2,384	$21,467	1.4%	-0.3%	$0.1	-$0.1
2038	$2,384	$21,443	1.4%	-0.3%	$0.1	-$0.1
2039	$2,384	$21,423	1.4%	-0.3%	$0.1	-$0.1
2040	$2,384	$21,409	1.4%	-0.3%	$0.1	-$0.1
NPV at 3%					$3.1	-$2.5
NPV at 7%					$1.7	-$1.4

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-4. Impact on C1 Tow/Tug/Push Vessel Market: >2,000 hp (Average Price per Vessel = $3,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2014	$0	-$53	0.0%	0.0%	$0.0	Loss less than $0.1
2015	$0	-$106	0.0%	0.0%	$0.3	-$0.3
2016	$4,675	$49,380	1.6%	-0.1%	$0.2	-$0.2
2017	$4,674	$49,214	1.6%	-0.1%	$0.1	-$0.1
2018	$4,673	$38,375	1.3%	-0.1%	$0.1	-$0.1
2019	$4,671	$38,155	1.3%	-0.1%	$0.1	-$0.1
2020	$4,669	$37,940	1.3%	-0.1%	$0.1	-$0.1
2021	$4,674	$37,732	1.3%	-0.1%	$0.1	-$0.1
2022	$4,672	$37,519	1.3%	-0.2%	$0.1	-$0.1
2023	$4,669	$37,440	1.2%	-0.2%	$0.1	-$0.1
2024	$4,673	$37,239	1.2%	-0.2%	$0.1	-$0.1
2025	$4,669	$37,032	1.2%	-0.2%	$0.1	-$0.1
2026	$4,672	$36,837	1.2%	-0.2%	$0.1	-$0.1
2027	$4,668	$36,638	1.2%	-0.2%	$0.1	$0.0
2028	$4,671	$36,450	1.2%	-0.3%	$0.1	$0.0
2029	$4,673	$36,403	1.2%	-0.3%	$0.1	$0.0
2030	$4,675	$36,244	1.2%	-0.3%	$0.1	$0.0
2031	$4,669	$36,091	1.2%	-0.3%	$0.1	$0.0
2032	$4,670	$35,958	1.2%	-0.3%	$0.1	$0.0
2033	$4,671	$35,951	1.2%	-0.3%	$0.1	$0.0
2034	$4,671	$35,827	1.2%	-0.3%	$0.1	$0.0
2035	$4,671	$35,708	1.2%	-0.3%	$0.1	-$0.1
2036	$4,670	$35,709	1.2%	-0.3%	$0.1	-$0.1
2037	$4,670	$35,604	1.2%	-0.3%	$0.1	-$0.1
2038	$4,668	$35,621	1.2%	-0.3%	$0.1	-$0.1
2039	$4,673	$35,539	1.2%	-0.3%	$0.1	-$0.1
2040	$4,672	$35,459	1.2%	-0.3%	$0.1	-$0.1
NPV at 3%					$1.5	-$1.1
NPV at 7%					$0.8	-$0.6

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-5. Impact on C2 Tow/Tug/Push Vessel Market: 800–2,000 hp (Average Price per Vessel = $2,325,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2014	$0	-$45	0.0%	0.0%	$0.0	Loss less than $0.1
2015	$0	-$89	0.0%	0.0%	$0.5	-$0.5
2016	$3,960	$138,748	6.0%	-0.1%	$0.3	-$0.3
2017	$3,967	$138,497	6.0%	-0.1%	$0.2	-$0.2
2018	$3,963	$106,330	4.6%	-0.1%	$0.1	-$0.1
2019	$3,969	$106,067	4.6%	-0.1%	$0.1	-$0.1
2020	$3,965	$105,799	4.6%	-0.1%	$0.1	-$0.1
2021	$3,960	$105,539	4.6%	-0.1%	$0.1	-$0.1
2022	$3,965	$105,290	4.6%	-0.2%	$0.1	-$0.1
2023	$3,960	$105,038	4.6%	-0.2%	$0.1	-$0.1
2024	$3,964	$104,798	4.6%	-0.2%	$0.1	-$0.1
2025	$3,968	$104,564	4.5%	-0.2%	$0.1	-$0.1
2026	$3,962	$104,327	4.5%	-0.2%	$0.1	-$0.1
2027	$3,966	$105,410	4.6%	-0.2%	$0.0	Loss less than $0.1
2028	$3,969	$105,181	4.6%	-0.3%	$0.0	Loss less than $0.1
2029	$3,962	$104,955	4.6%	-0.3%	$0.0	Loss less than $0.1
2030	$3,964	$104,759	4.6%	-0.3%	$0.0	Loss less than $0.1
2031	$3,966	$104,574	4.5%	-0.3%	$0.0	Loss less than $0.1
2032	$3,968	$104,403	4.5%	-0.3%	$0.0	Loss less than $0.1
2033	$3,960	$104,230	4.5%	-0.3%	$0.0	Loss less than $0.1
2034	$3,961	$104,070	4.5%	-0.3%	$0.0	Loss less than $0.1
2035	$3,961	$103,917	4.5%	-0.3%	$0.0	Loss less than $0.1
2036	$3,962	$103,770	4.5%	-0.3%	$0.0	Loss less than $0.1
2037	$3,962	$103,635	4.5%	-0.3%	$0.0	Loss less than $0.1
2038	$3,962	$103,510	4.5%	-0.3%	$0.0	Loss less than $0.1
2039	$3,961	$103,396	4.5%	-0.3%	$0.0	Loss less than $0.1
2040	$3,960	$103,287	4.5%	-0.3%	$0.0	Loss less than $0.1
NPV at 3%					$1.7	-$1.4
NPV at 7%					$1.0	-$0.8

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-6. Impact on C2 Tow/Tug/Push Vessel Market: >2,000 hp (Average Price per Vessel = $4,500,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2014	$0	-$90	0.0%	0.0%	$0.0	Loss less than $0.1
2015	$0	-$178	0.0%	0.0%	$1.9	-$1.9
2016	$7,154	$218,206	4.8%	-0.1%	$1.4	-$1.1
2017	$7,154	$217,926	4.8%	-0.1%	$1.0	-$0.8
2018	$7,156	$167,280	3.7%	-0.1%	$0.6	-$0.4
2019	$7,154	$166,921	3.7%	-0.1%	$0.6	-$0.4
2020	$7,155	$166,572	3.7%	-0.1%	$0.6	-$0.4
2021	$7,155	$166,229	3.7%	-0.1%	$0.7	-$0.5
2022	$7,154	$165,895	3.7%	-0.2%	$0.7	-$0.5
2023	$7,156	$165,570	3.7%	-0.2%	$0.7	-$0.5
2024	$7,154	$165,251	3.7%	-0.2%	$0.7	-$0.5
2025	$7,154	$164,943	3.7%	-0.2%	$0.7	-$0.5
2026	$7,154	$164,644	3.7%	-0.2%	$0.7	-$0.5
2027	$7,155	$164,356	3.7%	-0.2%	$0.3	-$0.2
2028	$7,154	$164,079	3.6%	-0.3%	$0.3	-$0.2
2029	$7,154	$163,832	3.6%	-0.3%	$0.3	-$0.2
2030	$7,154	$163,613	3.6%	-0.3%	$0.3	-$0.2
2031	$7,155	$163,422	3.6%	-0.3%	$0.3	-$0.2
2032	$7,154	$163,254	3.6%	-0.3%	$0.3	-$0.2
2033	$7,154	$163,099	3.6%	-0.3%	$0.3	-$0.2
2034	$7,154	$162,956	3.6%	-0.3%	$0.3	-$0.2
2035	$7,155	$162,826	3.6%	-0.3%	$0.3	-$0.2
2036	$7,154	$162,704	3.6%	-0.3%	$0.3	-$0.2
2037	$7,154	$162,604	3.6%	-0.3%	$0.3	-$0.2
2038	$7,154	$162,522	3.6%	-0.3%	$0.3	-$0.3
2039	$7,155	$162,462	3.6%	-0.3%	$0.3	-$0.3
2040	$7,154	$162,413	3.6%	-0.3%	$0.3	-$0.3
NPV at 3%					$8.6	-$6.7
NPV at 7%					$4.6	-$3.6

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-7. Impact on C1 Ferries Vessel Market: 800–2,000 hp (Average Price per Vessel = $1,550,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	$0.0	Loss less than $0.1
2014	$0	-$27	0.0%	0.0%	$0.0	Loss less than $0.1
2015	$0	-$55	0.0%	0.0%	$0.1	-$0.1
2016	$2,391	$29,437	1.9%	-0.1%	$0.1	-$0.1
2017	$2,388	$29,348	1.9%	-0.1%	$0.1	Loss less than $0.1
2018	$2,384	$22,899	1.5%	-0.1%	$0.0	Loss less than $0.1
2019	$2,380	$22,786	1.5%	-0.1%	$0.0	Loss less than $0.1
2020	$2,376	$22,675	1.5%	-0.1%	$0.0	Loss less than $0.1
2021	$2,390	$22,583	1.5%	-0.1%	$0.0	Loss less than $0.1
2022	$2,385	$22,476	1.5%	-0.2%	$0.0	Loss less than $0.1
2023	$2,381	$22,372	1.4%	-0.2%	$0.0	Loss less than $0.1
2024	$2,393	$22,287	1.4%	-0.2%	$0.0	Loss less than $0.1
2025	$2,388	$22,188	1.4%	-0.2%	$0.0	Loss less than $0.1
2026	$2,384	$22,092	1.4%	-0.2%	$0.0	Loss less than $0.1
2027	$2,379	$21,998	1.4%	-0.2%	$0.0	Loss less than $0.1
2028	$2,390	$21,925	1.4%	-0.3%	$0.0	Loss less than $0.1
2029	$2,384	$21,843	1.4%	-0.3%	$0.0	Loss less than $0.1
2030	$2,379	$21,771	1.4%	-0.3%	$0.0	Loss less than $0.1
2031	$2,389	$21,723	1.4%	-0.3%	$0.0	Loss less than $0.1
2032	$2,383	$21,665	1.4%	-0.3%	$0.0	Loss less than $0.1
2033	$2,378	$21,612	1.4%	-0.3%	$0.0	Loss less than $0.1
2034	$2,387	$21,578	1.4%	-0.3%	$0.0	Loss less than $0.1
2035	$2,381	$21,531	1.4%	-0.3%	$0.0	Loss less than $0.1
2036	$2,390	$21,503	1.4%	-0.3%	$0.0	Loss less than $0.1
2037	$2,383	$21,466	1.4%	-0.3%	$0.0	Loss less than $0.1
2038	$2,392	$21,450	1.4%	-0.3%	$0.0	Loss less than $0.1
2039	$2,385	$21,423	1.4%	-0.3%	$0.0	Loss less than $0.1
2040	$2,378	$21,403	1.4%	-0.3%	$0.0	Loss less than $0.1
NPV at 3%					$0.5	-$0.4
NPV at 7%					$0.3	-$0.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-8. Impact on C1 Ferries Vessel Market: >2,000 hp (Average Price per Vessel = $3,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$53	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$106	0.0%	0.0%	<$0.1	Loss less than $0.1
2016	$4,657	$49,362	1.6%	-0.1%	<$0.1	Loss less than $0.1
2017	$4,666	$49,206	1.6%	-0.1%	<$0.1	Loss less than $0.1
2018	$4,674	$38,376	1.3%	-0.1%	<$0.1	Loss less than $0.1
2019	$4,682	$38,167	1.3%	-0.1%	<$0.1	Loss less than $0.1
2020	$4,690	$37,961	1.3%	-0.1%	<$0.1	Loss less than $0.1
2021	$4,648	$37,706	1.3%	-0.1%	<$0.1	Loss less than $0.1
2022	$4,655	$37,503	1.3%	-0.2%	<$0.1	Loss less than $0.1
2023	$4,662	$37,433	1.2%	-0.2%	<$0.1	Loss less than $0.1
2024	$4,668	$37,234	1.2%	-0.2%	<$0.1	Loss less than $0.1
2025	$4,673	$37,037	1.2%	-0.2%	<$0.1	Loss less than $0.1
2026	$4,679	$36,843	1.2%	-0.2%	<$0.1	Loss less than $0.1
2027	$4,683	$36,653	1.2%	-0.2%	<$0.1	Loss less than $0.1
2028	$4,687	$36,467	1.2%	-0.3%	<$0.1	Loss less than $0.1
2029	$4,691	$36,421	1.2%	-0.3%	<$0.1	Loss less than $0.1
2030	$4,649	$36,219	1.2%	-0.3%	<$0.1	Loss less than $0.1
2031	$4,653	$36,075	1.2%	-0.3%	<$0.1	Loss less than $0.1
2032	$4,655	$35,944	1.2%	-0.3%	<$0.1	Loss less than $0.1
2033	$4,658	$35,938	1.2%	-0.3%	<$0.1	Loss less than $0.1
2034	$4,660	$35,816	1.2%	-0.3%	<$0.1	Loss less than $0.1
2035	$4,661	$35,699	1.2%	-0.3%	<$0.1	Loss less than $0.1
2036	$4,663	$35,701	1.2%	-0.3%	<$0.1	Loss less than $0.1
2037	$4,663	$35,597	1.2%	-0.3%	<$0.1	Loss less than $0.1
2038	$4,664	$35,617	1.2%	-0.3%	<$0.1	Loss less than $0.1
2039	$4,664	$35,530	1.2%	-0.3%	<$0.1	Loss less than $0.1
2040	$4,664	$35,451	1.2%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.2	-$0.2
NPV at 7%					$0.1	-$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-9. Impact on C2 Ferries Vessel Market: 800–2,000 hp (Average Price per Vessel = $2,325,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$45	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$89	0.0%	0.0%	<$0.1	Loss less than $0.1
2016	$3,946	$138,733	6.0%	-0.1%	<$0.1	Loss less than $0.1
2017	$3,910	$138,440	6.0%	-0.1%	<$0.1	Loss less than $0.1
2018	$3,986	$106,353	4.6%	-0.1%	<$0.1	Loss less than $0.1
2019	$3,951	$106,048	4.6%	-0.1%	<$0.1	Loss less than $0.1
2020	$3,915	$105,750	4.6%	-0.1%	<$0.1	Loss less than $0.1
2021	$3,988	$105,567	4.6%	-0.1%	<$0.1	Loss less than $0.1
2022	$3,953	$105,277	4.6%	-0.2%	<$0.1	Loss less than $0.1
2023	$3,917	$104,995	4.6%	-0.2%	<$0.1	Loss less than $0.1
2024	$3,987	$104,821	4.6%	-0.2%	<$0.1	Loss less than $0.1
2025	$3,952	$104,547	4.5%	-0.2%	<$0.1	Loss less than $0.1
2026	$3,917	$104,281	4.5%	-0.2%	<$0.1	Loss less than $0.1
2027	$3,984	$105,428	4.6%	-0.2%	<$0.1	Loss less than $0.1
2028	$3,948	$105,161	4.6%	-0.3%	<$0.1	Loss less than $0.1
2029	$4,013	$105,007	4.6%	-0.3%	<$0.1	Loss less than $0.1
2030	$3,978	$104,773	4.6%	-0.3%	<$0.1	Loss less than $0.1
2031	$3,942	$104,550	4.5%	-0.3%	<$0.1	Loss less than $0.1
2032	$4,005	$104,440	4.5%	-0.3%	<$0.1	Loss less than $0.1
2033	$3,969	$104,239	4.5%	-0.3%	<$0.1	Loss less than $0.1
2034	$3,934	$104,043	4.5%	-0.3%	<$0.1	Loss less than $0.1
2035	$3,994	$103,949	4.5%	-0.3%	<$0.1	Loss less than $0.1
2036	$3,958	$103,766	4.5%	-0.3%	<$0.1	Loss less than $0.1
2037	$3,923	$103,596	4.5%	-0.3%	<$0.1	Loss less than $0.1
2038	$3,980	$103,529	4.5%	-0.3%	<$0.1	Loss less than $0.1
2039	$3,945	$103,380	4.5%	-0.3%	<$0.1	Loss less than $0.1
2040	$4,000	$103,327	4.5%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.2	-$0.1
NPV at 7%					$0.1	-$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-10. Impact on C2 Ferries Vessel Market: >2,000 hp (Average Price per Vessel = $4,500,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$90	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$178	0.0%	0.0%	$0.2	-$0.2
2016	$7,158	$218,210	4.8%	-0.1%	$0.1	-$0.1
2017	$7,150	$217,923	4.8%	-0.1%	$0.1	-$0.1
2018	$7,142	$167,266	3.7%	-0.1%	$0.1	Loss less than $0.1
2019	$7,161	$166,927	3.7%	-0.1%	$0.1	Loss less than $0.1
2020	$7,151	$166,568	3.7%	-0.1%	$0.1	Loss less than $0.1
2021	$7,141	$166,216	3.7%	-0.1%	$0.1	Loss less than $0.1
2022	$7,158	$165,898	3.7%	-0.2%	$0.1	Loss less than $0.1
2023	$7,147	$165,561	3.7%	-0.2%	$0.1	Loss less than $0.1
2024	$7,162	$165,258	3.7%	-0.2%	$0.1	Loss less than $0.1
2025	$7,150	$164,939	3.7%	-0.2%	$0.1	Loss less than $0.1
2026	$7,163	$164,653	3.7%	-0.2%	$0.1	Loss less than $0.1
2027	$7,150	$164,352	3.7%	-0.2%	<$0.1	Loss less than $0.1
2028	$7,163	$164,088	3.6%	-0.3%	<$0.1	Loss less than $0.1
2029	$7,149	$163,827	3.6%	-0.3%	<$0.1	Loss less than $0.1
2030	$7,160	$163,619	3.6%	-0.3%	<$0.1	Loss less than $0.1
2031	$7,145	$163,412	3.6%	-0.3%	<$0.1	Loss less than $0.1
2032	$7,155	$163,255	3.6%	-0.3%	<$0.1	Loss less than $0.1
2033	$7,163	$163,108	3.6%	-0.3%	<$0.1	Loss less than $0.1
2034	$7,147	$162,950	3.6%	-0.3%	<$0.1	Loss less than $0.1
2035	$7,155	$162,825	3.6%	-0.3%	<$0.1	Loss less than $0.1
2036	$7,162	$162,712	3.6%	-0.3%	<$0.1	Loss less than $0.1
2037	$7,145	$162,594	3.6%	-0.3%	<$0.1	Loss less than $0.1
2038	$7,150	$162,519	3.6%	-0.3%	<$0.1	Loss less than $0.1
2039	$7,155	$162,462	3.6%	-0.3%	<$0.1	Loss less than $0.1
2040	$7,160	$162,419	3.6%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.8	-$0.6
NPV at 7%					$0.4	-$0.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-11. Impact on C1 Supply/Crew Vessel Market: 800–2,000 hp (Average Price per Vessel = $3,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$55	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$108	0.0%	0.0%	$0.1	-$0.1
2016	$2,385	$29,105	0.9%	-0.1%	$0.1	-$0.1
2017	$2,381	$28,931	0.9%	-0.1%	$0.1	Loss less than $0.1
2018	$2,377	$22,414	0.7%	-0.1%	<$0.1	Loss less than $0.1
2019	$2,389	$22,209	0.7%	-0.1%	<$0.1	Loss less than $0.1
2020	$2,384	$21,991	0.7%	-0.1%	<$0.1	Loss less than $0.1
2021	$2,380	$21,778	0.7%	-0.1%	<$0.1	Loss less than $0.1
2022	$2,391	$21,587	0.7%	-0.2%	<$0.1	Loss less than $0.1
2023	$2,386	$21,384	0.7%	-0.2%	<$0.1	Loss less than $0.1
2024	$2,381	$21,186	0.7%	-0.2%	<$0.1	Loss less than $0.1
2025	$2,392	$21,009	0.7%	-0.2%	<$0.1	Loss less than $0.1
2026	$2,386	$20,822	0.7%	-0.2%	<$0.1	Loss less than $0.1
2027	$2,380	$20,640	0.7%	-0.2%	<$0.1	Loss less than $0.1
2028	$2,390	$20,482	0.7%	-0.3%	<$0.1	Loss less than $0.1
2029	$2,384	$20,326	0.7%	-0.3%	<$0.1	Loss less than $0.1
2030	$2,378	$20,187	0.7%	-0.3%	<$0.1	Loss less than $0.1
2031	$2,387	$20,079	0.6%	-0.3%	<$0.1	Loss less than $0.1
2032	$2,381	$19,971	0.6%	-0.3%	<$0.1	Loss less than $0.1
2033	$2,389	$19,886	0.6%	-0.3%	<$0.1	Loss less than $0.1
2034	$2,383	$19,792	0.6%	-0.3%	<$0.1	Loss less than $0.1
2035	$2,391	$19,720	0.6%	-0.3%	<$0.1	Loss less than $0.1
2036	$2,384	$19,640	0.6%	-0.3%	<$0.1	Loss less than $0.1
2037	$2,391	$19,586	0.6%	-0.3%	<$0.1	Loss less than $0.1
2038	$2,384	$19,529	0.6%	-0.3%	<$0.1	Loss less than $0.1
2039	$2,391	$19,498	0.6%	-0.3%	<$0.1	Loss less than $0.1
2040	$2,384	$19,463	0.6%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.5	-$0.5
NPV at 7%					$0.3	-$0.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-12. Impact on C1 Supply/Crew Vessel Market: >2,000 hp (Average Price per Vessel = $6,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	$0.0	$0.0
2008	$0	$0	0.0%	0.0%	$0.0	$0.0
2009	$0	$0	0.0%	0.0%	$0.0	$0.0
2010	$0	$0	0.0%	0.0%	$0.0	$0.0
2011	$0	$0	0.0%	0.0%	$0.0	$0.0
2012	$0	$0	0.0%	0.0%	$0.0	$0.0
2013	$0	$0	0.0%	0.0%	$0.0	$0.0
2014	$0	–$402	0.0%	0.0%	$0.0	$0.0
2015	$0	–$799	0.0%	0.0%	$0.8	–$0.8
2016	$4,671	$45,225	0.8%	–0.3%	$0.6	–$0.6
2017	$4,672	$43,974	0.7%	–0.3%	$0.4	–$0.5
2018	$4,673	$32,249	0.5%	–0.4%	$0.3	–$0.4
2019	$4,670	$30,635	0.5%	–0.4%	$0.3	–$0.4
2020	$4,673	$29,061	0.5%	–0.5%	$0.3	–$0.5
2021	$4,672	$27,513	0.5%	–0.6%	$0.3	–$0.6
2022	$4,671	$26,001	0.4%	–0.6%	$0.3	–$0.6
2023	$4,673	$24,663	0.4%	–0.7%	$0.3	–$0.7
2024	$4,671	$23,221	0.4%	–0.8%	$0.3	–$0.7
2025	$4,672	$21,819	0.4%	–0.8%	$0.3	–$0.8
2026	$4,673	$20,457	0.3%	–0.9%	$0.3	–$0.8
2027	$4,673	$19,136	0.3%	–0.9%	$0.2	–$0.7
2028	$4,672	$17,870	0.3%	–1.0%	$0.2	–$0.8
2029	$4,672	$16,860	0.3%	–1.0%	$0.2	–$0.8
2030	$4,671	$15,846	0.3%	–1.1%	$0.2	–$0.9
2031	$4,672	$14,953	0.2%	–1.1%	$0.2	–$0.9
2032	$4,673	$14,166	0.2%	–1.1%	$0.2	–$0.9
2033	$4,671	$13,556	0.2%	–1.2%	$0.2	–$1.0
2034	$4,671	$12,875	0.2%	–1.2%	$0.2	–$1.0
2035	$4,671	$12,242	0.2%	–1.2%	$0.2	–$1.0
2036	$4,673	$11,778	0.2%	–1.2%	$0.2	–$1.1
2037	$4,672	$11,279	0.2%	–1.3%	$0.2	–$1.1
2038	$4,670	$10,982	0.2%	–1.3%	$0.2	–$1.1
2039	$4,671	$10,651	0.2%	–1.3%	$0.2	–$1.1
2040	$4,672	$10,391	0.2%	–1.3%	$0.2	–$1.2
NPV at 3%					$3.9	–$10.5
NPV at 7%					$2.1	–$4.6

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-13. Impact on C2 Supply/Crew Vessel Market: 800–2,000 hp (Average Price per Vessel = $2,325,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$45	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$89	0.0%	0.0%	$0.3	-$0.3
2016	$3,967	$138,755	6.0%	-0.1%	$0.2	-$0.2
2017	$3,969	$138,498	6.0%	-0.1%	$0.1	-$0.1
2018	$3,970	$106,337	4.6%	-0.1%	$0.1	-$0.1
2019	$3,971	$106,068	4.6%	-0.1%	$0.1	-$0.1
2020	$3,972	$105,806	4.6%	-0.1%	$0.1	-$0.1
2021	$3,972	$105,551	4.6%	-0.1%	$0.1	-$0.1
2022	$3,972	$105,297	4.6%	-0.2%	$0.1	-$0.1
2023	$3,972	$105,050	4.6%	-0.2%	$0.1	-$0.1
2024	$3,971	$104,804	4.6%	-0.2%	$0.1	-$0.1
2025	$3,970	$104,566	4.5%	-0.2%	$0.1	-$0.1
2026	$3,969	$104,334	4.5%	-0.2%	$0.1	-$0.1
2027	$3,968	$105,412	4.6%	-0.2%	<$0.1	Loss less than $0.1
2028	$3,966	$105,178	4.6%	-0.3%	<$0.1	Loss less than $0.1
2029	$3,964	$104,957	4.6%	-0.3%	<$0.1	Loss less than $0.1
2030	$3,961	$104,757	4.6%	-0.3%	<$0.1	Loss less than $0.1
2031	$3,959	$104,567	4.5%	-0.3%	<$0.1	Loss less than $0.1
2032	$3,972	$104,407	4.5%	-0.3%	<$0.1	Loss less than $0.1
2033	$3,969	$104,239	4.5%	-0.3%	<$0.1	Loss less than $0.1
2034	$3,965	$104,075	4.5%	-0.3%	<$0.1	Loss less than $0.1
2035	$3,962	$103,917	4.5%	-0.3%	<$0.1	Loss less than $0.1
2036	$3,958	$103,766	4.5%	-0.3%	<$0.1	Loss less than $0.1
2037	$3,969	$103,642	4.5%	-0.3%	<$0.1	Loss less than $0.1
2038	$3,964	$103,513	4.5%	-0.3%	<$0.1	Loss less than $0.1
2039	$3,959	$103,394	4.5%	-0.3%	<$0.1	Loss less than $0.1
2040	$3,969	$103,296	4.5%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$1.0	-$0.8
NPV at 7%					$0.5	-$0.5

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-14. Impact on C2 Supply/Crew Vessel Market: >2,000 hp (Average Price per Vessel = $4,500,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$90	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$178	0.0%	0.0%	$1.1	-$1.1
2016	$7,153	$218,205	4.8%	-0.1%	$0.8	-$0.7
2017	$7,154	$217,926	4.8%	-0.1%	$0.6	-$0.4
2018	$7,154	$167,278	3.7%	-0.1%	$0.4	-$0.2
2019	$7,154	$166,921	3.7%	-0.1%	$0.4	-$0.2
2020	$7,154	$166,571	3.7%	-0.1%	$0.4	-$0.3
2021	$7,152	$166,227	3.7%	-0.1%	$0.4	-$0.3
2022	$7,155	$165,896	3.7%	-0.2%	$0.4	-$0.3
2023	$7,153	$165,567	3.7%	-0.2%	$0.4	-$0.3
2024	$7,154	$165,251	3.7%	-0.2%	$0.4	-$0.3
2025	$7,155	$164,944	3.7%	-0.2%	$0.4	-$0.3
2026	$7,156	$164,646	3.7%	-0.2%	$0.4	-$0.3
2027	$7,155	$164,357	3.7%	-0.2%	$0.2	-$0.1
2028	$7,155	$164,080	3.6%	-0.3%	$0.2	-$0.1
2029	$7,153	$163,831	3.6%	-0.3%	$0.2	-$0.1
2030	$7,155	$163,614	3.6%	-0.3%	$0.2	-$0.1
2031	$7,153	$163,420	3.6%	-0.3%	$0.2	-$0.1
2032	$7,154	$163,254	3.6%	-0.3%	$0.2	-$0.1
2033	$7,154	$163,099	3.6%	-0.3%	$0.2	-$0.1
2034	$7,154	$162,957	3.6%	-0.3%	$0.2	-$0.1
2035	$7,154	$162,824	3.6%	-0.3%	$0.2	-$0.1
2036	$7,156	$162,706	3.6%	-0.3%	$0.2	-$0.1
2037	$7,155	$162,604	3.6%	-0.3%	$0.2	-$0.1
2038	$7,156	$162,524	3.6%	-0.3%	$0.2	-$0.1
2039	$7,153	$162,459	3.6%	-0.3%	$0.2	-$0.1
2040	$7,153	$162,412	3.6%	-0.3%	$0.2	-$0.1
NPV at 3%					$4.9	-$3.8
NPV at 7%					$2.6	-$2.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-15. Impact on C1 Cargo Vessel Market: 800–2,000 hp (Average Price per Vessel = $3,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$55	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$108	0.0%	0.0%	<$0.1	Loss less than $0.1
2016	$2,400	$29,119	0.9%	-0.1%	<$0.1	Loss less than $0.1
2017	$2,378	$28,928	0.9%	-0.1%	<$0.1	Loss less than $0.1
2018	$2,412	$22,449	0.7%	-0.1%	<$0.1	Loss less than $0.1
2019	$2,390	$22,210	0.7%	-0.1%	<$0.1	Loss less than $0.1
2020	$2,369	$21,976	0.7%	-0.1%	<$0.1	Loss less than $0.1
2021	$2,401	$21,800	0.7%	-0.1%	<$0.1	Loss less than $0.1
2022	$2,380	$21,576	0.7%	-0.2%	<$0.1	Loss less than $0.1
2023	$2,411	$21,409	0.7%	-0.2%	<$0.1	Loss less than $0.1
2024	$2,390	$21,194	0.7%	-0.2%	<$0.1	Loss less than $0.1
2025	$2,368	$20,986	0.7%	-0.2%	<$0.1	Loss less than $0.1
2026	$2,398	$20,834	0.7%	-0.2%	<$0.1	Loss less than $0.1
2027	$2,377	$20,637	0.7%	-0.2%	<$0.1	Loss less than $0.1
2028	$2,406	$20,498	0.7%	-0.3%	<$0.1	Loss less than $0.1
2029	$2,384	$20,326	0.7%	-0.3%	<$0.1	Loss less than $0.1
2030	$2,363	$20,172	0.7%	-0.3%	<$0.1	Loss less than $0.1
2031	$2,391	$20,083	0.6%	-0.3%	<$0.1	Loss less than $0.1
2032	$2,369	$19,959	0.6%	-0.3%	<$0.1	Loss less than $0.1
2033	$2,396	$19,892	0.6%	-0.3%	<$0.1	Loss less than $0.1
2034	$2,375	$19,784	0.6%	-0.3%	<$0.1	Loss less than $0.1
2035	$2,401	$19,730	0.6%	-0.3%	<$0.1	Loss less than $0.1
2036	$2,379	$19,635	0.6%	-0.3%	<$0.1	Loss less than $0.1
2037	$2,404	$19,599	0.6%	-0.3%	<$0.1	Loss less than $0.1
2038	$2,383	$19,528	0.6%	-0.3%	<$0.1	Loss less than $0.1
2039	$2,407	$19,514	0.6%	-0.3%	<$0.1	Loss less than $0.1
2040	$2,386	$19,465	0.6%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.2	-$0.2
NPV at 7%					$0.1	-$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-16. Impact on C1 Cargo Vessel Market: >2,000 hp (Average Price per Vessel = $6,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$106	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$210	0.0%	0.0%	<$0.1	Loss less than $0.1
2016	$4,606	$48,681	0.8%	-0.1%	<$0.1	Loss less than $0.1
2017	$4,723	$48,469	0.8%	-0.1%	<$0.1	Loss less than $0.1
2018	$4,681	$37,458	0.6%	-0.1%	<$0.1	Loss less than $0.1
2019	$4,639	$36,989	0.6%	-0.1%	<$0.1	Loss less than $0.1
2020	$4,598	$36,530	0.6%	-0.1%	<$0.1	Loss less than $0.1
2021	$4,708	$36,227	0.6%	-0.1%	<$0.1	Loss less than $0.1
2022	$4,666	$35,780	0.6%	-0.2%	<$0.1	Loss less than $0.1
2023	$4,625	$35,473	0.6%	-0.2%	<$0.1	Loss less than $0.1
2024	$4,731	$35,189	0.6%	-0.2%	<$0.1	Loss less than $0.1
2025	$4,689	$34,764	0.6%	-0.2%	<$0.1	Loss less than $0.1
2026	$4,647	$34,349	0.6%	-0.2%	<$0.1	Loss less than $0.1
2027	$4,606	$33,944	0.6%	-0.2%	<$0.1	Loss less than $0.1
2028	$4,707	$33,694	0.6%	-0.3%	<$0.1	Loss less than $0.1
2029	$4,665	$33,458	0.6%	-0.3%	<$0.1	Loss less than $0.1
2030	$4,624	$33,128	0.6%	-0.3%	<$0.1	Loss less than $0.1
2031	$4,721	$32,967	0.5%	-0.3%	<$0.1	Loss less than $0.1
2032	$4,679	$32,693	0.5%	-0.3%	<$0.1	Loss less than $0.1
2033	$4,638	$32,553	0.5%	-0.3%	<$0.1	Loss less than $0.1
2034	$4,731	$32,439	0.5%	-0.3%	<$0.1	Loss less than $0.1
2035	$4,689	$32,201	0.5%	-0.3%	<$0.1	Loss less than $0.1
2036	$4,647	$32,090	0.5%	-0.3%	<$0.1	Loss less than $0.1
2037	$4,606	$31,885	0.5%	-0.3%	<$0.1	Loss less than $0.1
2038	$4,695	$31,946	0.5%	-0.3%	<$0.1	Loss less than $0.1
2039	$4,653	$31,781	0.5%	-0.3%	<$0.1	Loss less than $0.1
2040	$4,612	$31,634	0.5%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.1	-$0.1
NPV at 7%					<$0.1	Loss less than $0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-17. Impact on C2 Cargo Vessel Market: 800–2,000 hp (Average Price per Vessel = $4,650,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$85	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$169	0.0%	0.0%	$0.1	-$0.1
2016	$3,972	$138,276	3.0%	-0.1%	<$0.1	Loss less than $0.1
2017	$3,937	$137,857	3.0%	-0.1%	<$0.1	Loss less than $0.1
2018	$3,972	$105,630	2.3%	-0.1%	<$0.1	Loss less than $0.1
2019	$3,937	$105,165	2.3%	-0.1%	<$0.1	Loss less than $0.1
2020	$3,971	$104,780	2.3%	-0.1%	<$0.1	Loss less than $0.1
2021	$3,936	$104,335	2.3%	-0.1%	<$0.1	Loss less than $0.1
2022	$3,969	$103,965	2.3%	-0.2%	<$0.1	Loss less than $0.1
2023	$3,934	$103,537	2.3%	-0.2%	<$0.1	Loss less than $0.1
2024	$3,966	$103,183	2.2%	-0.2%	<$0.1	Loss less than $0.1
2025	$3,997	$102,838	2.2%	-0.2%	<$0.1	Loss less than $0.1
2026	$3,962	$102,438	2.2%	-0.2%	<$0.1	Loss less than $0.1
2027	$3,992	$103,418	2.2%	-0.2%	<$0.1	Loss less than $0.1
2028	$3,956	$103,027	2.2%	-0.3%	<$0.1	Loss less than $0.1
2029	$3,985	$102,727	2.2%	-0.3%	<$0.1	Loss less than $0.1
2030	$3,950	$102,395	2.2%	-0.3%	<$0.1	Loss less than $0.1
2031	$3,978	$102,150	2.2%	-0.3%	<$0.1	Loss less than $0.1
2032	$3,942	$101,866	2.2%	-0.3%	<$0.1	Loss less than $0.1
2033	$3,969	$101,659	2.2%	-0.3%	<$0.1	Loss less than $0.1
2034	$3,995	$101,460	2.2%	-0.3%	<$0.1	Loss less than $0.1
2035	$3,959	$101,212	2.2%	-0.3%	<$0.1	Loss less than $0.1
2036	$3,984	$101,036	2.2%	-0.3%	<$0.1	Loss less than $0.1
2037	$3,949	$100,820	2.2%	-0.3%	<$0.1	Loss less than $0.1
2038	$3,973	$100,684	2.2%	-0.3%	<$0.1	Loss less than $0.1
2039	$3,937	$100,506	2.2%	-0.3%	<$0.1	Loss less than $0.1
2040	$3,961	$100,400	2.2%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.3	-$0.2
NPV at 7%					$0.1	-$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-18. Impact on C2 Cargo Vessel Market: >2,000 hp (Average Price per Vessel = $9,000,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$168	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$334	0.0%	0.0%	$0.3	-$0.3
2016	$7,150	$217,255	2.4%	-0.1%	$0.2	-$0.2
2017	$7,157	$216,739	2.4%	-0.1%	$0.1	-$0.1
2018	$7,147	$165,883	1.8%	-0.1%	$0.1	-$0.1
2019	$7,153	$165,219	1.8%	-0.1%	$0.1	-$0.1
2020	$7,159	$164,568	1.8%	-0.1%	$0.1	-$0.1
2021	$7,147	$163,914	1.8%	-0.1%	$0.1	-$0.1
2022	$7,152	$163,292	1.8%	-0.2%	$0.1	-$0.1
2023	$7,156	$162,684	1.8%	-0.2%	$0.1	-$0.1
2024	$7,159	$162,093	1.8%	-0.2%	$0.1	-$0.1
2025	$7,162	$161,518	1.8%	-0.2%	$0.1	-$0.1
2026	$7,148	$160,943	1.8%	-0.2%	$0.1	-$0.1
2027	$7,149	$160,403	1.8%	-0.2%	<$0.1	Loss less than $0.1
2028	$7,150	$159,886	1.8%	-0.3%	<$0.1	-$0.1
2029	$7,151	$159,422	1.8%	-0.3%	<$0.1	-$0.1
2030	$7,151	$159,012	1.8%	-0.3%	<$0.1	-$0.1
2031	$7,150	$158,652	1.8%	-0.3%	<$0.1	-$0.1
2032	$7,149	$158,336	1.8%	-0.3%	<$0.1	-$0.1
2033	$7,147	$158,045	1.8%	-0.3%	<$0.1	-$0.1
2034	$7,160	$157,790	1.8%	-0.3%	<$0.1	-$0.1
2035	$7,157	$157,539	1.8%	-0.3%	<$0.1	-$0.1
2036	$7,154	$157,310	1.7%	-0.3%	<$0.1	-$0.1
2037	$7,150	$157,118	1.7%	-0.3%	<$0.1	-$0.1
2038	$7,160	$156,975	1.7%	-0.3%	<$0.1	-$0.1
2039	$7,155	$156,853	1.7%	-0.3%	<$0.1	-$0.1
2040	$7,149	$156,760	1.7%	-0.3%	<$0.1	-$0.1
NPV at 3%					$1.3	-$1.3
NPV at 7%					$0.7	-$0.7

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-19. Impact on C1 Other Commercial Vessel Market: 800–2,000 hp (Average Price per Vessel = \$1,085,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$19	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$38	0.0%	0.0%	$0.1	-$0.1
2016	$2,381	$29,525	2.7%	-0.1%	$0.1	-$0.1
2017	$2,383	$29,466	2.7%	-0.1%	<$0.1	Loss less than $0.1
2018	$2,384	$23,043	2.1%	-0.1%	<$0.1	Loss less than $0.1
2019	$2,385	$22,966	2.1%	-0.1%	<$0.1	Loss less than $0.1
2020	$2,386	$22,892	2.1%	-0.1%	<$0.1	Loss less than $0.1
2021	$2,386	$22,818	2.1%	-0.1%	<$0.1	Loss less than $0.1
2022	$2,387	$22,747	2.1%	-0.2%	<$0.1	Loss less than $0.1
2023	$2,387	$22,677	2.1%	-0.2%	<$0.1	Loss less than $0.1
2024	$2,387	$22,608	2.1%	-0.2%	<$0.1	Loss less than $0.1
2025	$2,387	$22,541	2.1%	-0.2%	<$0.1	Loss less than $0.1
2026	$2,386	$22,476	2.1%	-0.2%	<$0.1	Loss less than $0.1
2027	$2,386	$22,413	2.1%	-0.2%	<$0.1	Loss less than $0.1
2028	$2,385	$22,353	2.1%	-0.3%	<$0.1	Loss less than $0.1
2029	$2,384	$22,299	2.1%	-0.3%	<$0.1	Loss less than $0.1
2030	$2,383	$22,251	2.1%	-0.3%	<$0.1	Loss less than $0.1
2031	$2,382	$22,208	2.0%	-0.3%	<$0.1	Loss less than $0.1
2032	$2,381	$22,170	2.0%	-0.3%	<$0.1	Loss less than $0.1
2033	$2,379	$22,135	2.0%	-0.3%	<$0.1	Loss less than $0.1
2034	$2,377	$22,103	2.0%	-0.3%	<$0.1	Loss less than $0.1
2035	$2,375	$22,072	2.0%	-0.3%	<$0.1	Loss less than $0.1
2036	$2,392	$22,063	2.0%	-0.3%	<$0.1	Loss less than $0.1
2037	$2,390	$22,039	2.0%	-0.3%	<$0.1	Loss less than $0.1
2038	$2,388	$22,019	2.0%	-0.3%	<$0.1	Loss less than $0.1
2039	$2,385	$22,003	2.0%	-0.3%	<$0.1	Loss less than $0.1
2040	$2,382	$21,990	2.0%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.4	-$0.3
NPV at 7%					$0.2	-$0.2

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-20. Impact on C1 Other Commercial Vessel Market: >2,000 hp (Average Price per Vessel = $2,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$38	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$74	0.0%	0.0%	<$0.1	Loss less than $0.1
2016	$4,692	$49,587	2.4%	-0.1%	<$0.1	Loss less than $0.1
2017	$4,650	$49,428	2.4%	-0.1%	<$0.1	Loss less than $0.1
2018	$4,673	$38,652	1.8%	-0.1%	<$0.1	Loss less than $0.1
2019	$4,694	$38,519	1.8%	-0.1%	<$0.1	Loss less than $0.1
2020	$4,653	$38,325	1.8%	-0.1%	<$0.1	Loss less than $0.1
2021	$4,673	$38,192	1.8%	-0.1%	<$0.1	Loss less than $0.1
2022	$4,693	$38,061	1.8%	-0.2%	<$0.1	Loss less than $0.1
2023	$4,652	$38,000	1.8%	-0.2%	<$0.1	Loss less than $0.1
2024	$4,671	$37,870	1.8%	-0.2%	<$0.1	Loss less than $0.1
2025	$4,689	$37,739	1.8%	-0.2%	<$0.1	Loss less than $0.1
2026	$4,647	$37,551	1.8%	-0.2%	<$0.1	Loss less than $0.1
2027	$4,665	$37,424	1.8%	-0.2%	<$0.1	Loss less than $0.1
2028	$4,682	$37,299	1.8%	-0.3%	<$0.1	Loss less than $0.1
2029	$4,698	$37,310	1.8%	-0.3%	<$0.1	Loss less than $0.1
2030	$4,656	$37,145	1.8%	-0.3%	<$0.1	Loss less than $0.1
2031	$4,672	$37,047	1.8%	-0.3%	<$0.1	Loss less than $0.1
2032	$4,686	$36,957	1.8%	-0.3%	<$0.1	Loss less than $0.1
2033	$4,645	$36,934	1.8%	-0.3%	<$0.1	Loss less than $0.1
2034	$4,659	$36,850	1.8%	-0.3%	<$0.1	Loss less than $0.1
2035	$4,672	$36,767	1.8%	-0.3%	<$0.1	Loss less than $0.1
2036	$4,685	$36,803	1.8%	-0.3%	<$0.1	Loss less than $0.1
2037	$4,697	$36,727	1.7%	-0.3%	<$0.1	Loss less than $0.1
2038	$4,655	$36,719	1.7%	-0.3%	<$0.1	Loss less than $0.1
2039	$4,667	$36,654	1.7%	-0.3%	<$0.1	Loss less than $0.1
2040	$4,678	$36,595	1.7%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.2	-$0.1
NPV at 7%					$0.1	-$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-21. Impact on C2 Other Commercial Vessel Market: 800–2,000 hp (Average Price per Vessel = $1,627,500)^{a,b}

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$33	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$65	0.0%	0.0%	<$0.1	Loss less than $0.1
2016	$3,950	$138,883	8.6%	-0.1%	<$0.1	Loss less than $0.1
2017	$3,915	$138,627	8.6%	-0.1%	<$0.1	Loss less than $0.1
2018	$3,880	$106,460	6.6%	-0.1%	<$0.1	Loss less than $0.1
2019	$3,846	$106,204	6.6%	-0.1%	<$0.1	Loss less than $0.1
2020	$3,811	$105,954	6.6%	-0.1%	<$0.1	Loss less than $0.1
2021	$3,777	$105,710	6.6%	-0.1%	<$0.1	Loss less than $0.1
2022	$4,118	$105,841	6.6%	-0.2%	<$0.1	Loss less than $0.1
2023	$4,081	$105,601	6.6%	-0.2%	<$0.1	Loss less than $0.1
2024	$4,045	$105,363	6.5%	-0.2%	<$0.1	Loss less than $0.1
2025	$4,009	$105,131	6.5%	-0.2%	<$0.1	Loss less than $0.1
2026	$3,973	$104,904	6.5%	-0.2%	<$0.1	Loss less than $0.1
2027	$3,938	$105,987	6.6%	-0.2%	<$0.1	Loss less than $0.1
2028	$3,902	$105,757	6.6%	-0.3%	<$0.1	Loss less than $0.1
2029	$3,868	$105,537	6.6%	-0.3%	<$0.1	Loss less than $0.1
2030	$3,833	$105,334	6.5%	-0.3%	<$0.1	Loss less than $0.1
2031	$3,799	$105,138	6.5%	-0.3%	<$0.1	Loss less than $0.1
2032	$4,107	$105,296	6.5%	-0.3%	<$0.1	Loss less than $0.1
2033	$4,071	$105,115	6.5%	-0.3%	<$0.1	Loss less than $0.1
2034	$4,034	$104,937	6.5%	-0.3%	<$0.1	Loss less than $0.1
2035	$3,998	$104,764	6.5%	-0.3%	<$0.1	Loss less than $0.1
2036	$3,963	$104,598	6.5%	-0.3%	<$0.1	Loss less than $0.1
2037	$3,927	$104,441	6.5%	-0.3%	<$0.1	Loss less than $0.1
2038	$3,892	$104,293	6.5%	-0.3%	<$0.1	Loss less than $0.1
2039	$3,858	$104,153	6.5%	-0.3%	<$0.1	Loss less than $0.1
2040	$3,823	$104,016	6.5%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					<$0.1	Loss less than $0.1
NPV at 7%					<$0.1	Loss less than $0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-22. Impact on C2 Other Commercial Vessel Market: >2,000 hp (Average Price per Vessel = $3,150,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1
2014	$0	-$66	0.0%	0.0%	<$0.1	Loss less than $0.1
2015	$0	-$131	0.0%	0.0%	$0.1	-$0.1
2016	$7,111	$218,447	6.9%	-0.1%	<$0.1	Loss less than $0.1
2017	$7,145	$218,275	6.9%	-0.1%	<$0.1	Loss less than $0.1
2018	$7,178	$167,718	5.3%	-0.1%	<$0.1	Loss less than $0.1
2019	$7,114	$167,391	5.3%	-0.1%	<$0.1	Loss less than $0.1
2020	$7,146	$167,165	5.3%	-0.1%	<$0.1	Loss less than $0.1
2021	$7,177	$166,944	5.3%	-0.1%	<$0.1	Loss less than $0.1
2022	$7,113	$166,633	5.3%	-0.2%	<$0.1	Loss less than $0.1
2023	$7,142	$166,422	5.3%	-0.2%	<$0.1	Loss less than $0.1
2024	$7,170	$166,216	5.3%	-0.2%	<$0.1	Loss less than $0.1
2025	$7,197	$166,016	5.3%	-0.2%	<$0.1	Loss less than $0.1
2026	$7,133	$165,732	5.3%	-0.2%	<$0.1	Loss less than $0.1
2027	$7,159	$165,545	5.3%	-0.2%	<$0.1	Loss less than $0.1
2028	$7,184	$165,366	5.2%	-0.3%	<$0.1	Loss less than $0.1
2029	$7,120	$165,120	5.2%	-0.3%	<$0.1	Loss less than $0.1
2030	$7,144	$164,982	5.2%	-0.3%	<$0.1	Loss less than $0.1
2031	$7,166	$164,863	5.2%	-0.3%	<$0.1	Loss less than $0.1
2032	$7,188	$164,761	5.2%	-0.3%	<$0.1	Loss less than $0.1
2033	$7,124	$164,583	5.2%	-0.3%	<$0.1	Loss less than $0.1
2034	$7,144	$164,498	5.2%	-0.3%	<$0.1	Loss less than $0.1
2035	$7,164	$164,420	5.2%	-0.3%	<$0.1	Loss less than $0.1
2036	$7,182	$164,350	5.2%	-0.3%	<$0.1	Loss less than $0.1
2037	$7,118	$164,213	5.2%	-0.3%	<$0.1	Loss less than $0.1
2038	$7,136	$164,170	5.2%	-0.3%	<$0.1	Loss less than $0.1
2039	$7,153	$164,141	5.2%	-0.3%	<$0.1	Loss less than $0.1
2040	$7,169	$164,122	5.2%	-0.3%	<$0.1	Loss less than $0.1
NPV at 3%					$0.2	-$0.2
NPV at 7%					$0.1	-$0.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-23. Impact on C1 Fishing Vessel Market: 800–2,000 hp (Average Price per Vessel = $1,085,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Consumer Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2014	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2015	$0	$0	0.0%	0.0%	$8.0	-$8.0	Loss less than $0.1	-$7.96
2016	$2,385	$15,870	1.5%	-2.0%	$4.9	-$8.6	-$5.05	-$13.60
2017	$2,385	$15,869	1.5%	-2.0%	$3.0	-$6.7	-$5.09	-$11.77
2018	$2,385	$12,468	1.1%	-1.6%	$2.1	-$4.8	-$4.04	-$8.86
2019	$2,385	$12,467	1.1%	-1.6%	$2.1	-$4.8	-$4.08	-$8.92
2020	$2,385	$12,467	1.1%	-1.6%	$2.1	-$4.9	-$4.12	-$8.99
2021	$2,385	$12,466	1.1%	-1.6%	$2.1	-$4.9	-$4.15	-$9.06
2022	$2,385	$12,465	1.1%	-1.6%	$2.1	-$4.9	-$4.19	-$9.13
2023	$2,385	$12,464	1.1%	-1.6%	$2.1	-$5.0	-$4.23	-$9.20
2024	$2,385	$12,463	1.1%	-1.6%	$2.1	-$5.0	-$4.27	-$9.27
2025	$2,385	$12,462	1.1%	-1.6%	$2.1	-$5.0	-$4.30	-$9.34
2026	$2,385	$12,462	1.1%	-1.6%	$2.1	-$5.1	-$4.34	-$9.42
2027	$2,385	$12,461	1.1%	-1.6%	$0.8	-$3.8	-$4.38	-$8.21
2028	$2,385	$12,460	1.1%	-1.6%	$0.9	-$3.9	-$4.42	-$8.29
2029	$2,385	$12,460	1.1%	-1.6%	$0.9	-$3.9	-$4.46	-$8.36
2030	$2,385	$12,459	1.1%	-1.6%	$0.9	-$3.9	-$4.50	-$8.44
2031	$2,385	$12,459	1.1%	-1.6%	$0.9	-$4.0	-$4.54	-$8.51
2032	$2,385	$12,458	1.1%	-1.6%	$0.9	-$4.0	-$4.58	-$8.59
2033	$2,385	$12,458	1.1%	-1.6%	$0.9	-$4.0	-$4.62	-$8.67
2034	$2,385	$12,457	1.1%	-1.6%	$0.9	-$4.1	-$4.66	-$8.74
2035	$2,385	$12,457	1.1%	-1.6%	$0.9	-$4.1	-$4.71	-$8.82
2036	$2,385	$12,457	1.1%	-1.6%	$0.9	-$4.2	-$4.75	-$8.90
2037	$2,385	$12,457	1.1%	-1.6%	$0.9	-$4.2	-$4.79	-$8.98
2038	$2,385	$12,456	1.1%	-1.6%	$0.9	-$4.2	-$4.83	-$9.06
2039	$2,385	$12,456	1.1%	-1.6%	$0.9	-$4.3	-$4.88	-$9.14
2040	$2,385	$12,456	1.1%	-1.6%	$0.9	-$4.3	-$4.92	-$9.23
NPV at 3%					$28.4	-$68.3	-$58.2	-$126.5
NPV at 7%					$15.6	-$33.8	-$26.5	-$60.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-24. Impact on C1 Fishing Vessel Market: >2,000 hp (Average Price per Vessel = $2,100,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Consumer Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2014	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2015	$0	-$1	0.0%	0.0%	$2.8	-$2.8	Loss less than $0.1	-$2.80
2016	$4,672	$26,671	1.3%	-1.8%	$2.0	-$4.1	-$2.98	-$7.05
2017	$4,671	$26,670	1.3%	-1.8%	$1.3	-$3.4	-$3.01	-$6.43
2018	$4,672	$20,959	1.0%	-1.4%	$1.0	-$2.5	-$2.39	-$4.93
2019	$4,671	$20,955	1.0%	-1.4%	$1.0	-$2.6	-$2.41	-$4.97
2020	$4,671	$20,950	1.0%	-1.4%	$1.0	-$2.6	-$2.43	-$5.01
2021	$4,671	$20,942	1.0%	-1.4%	$1.0	-$2.6	-$2.45	-$5.05
2022	$4,672	$20,935	1.0%	-1.4%	$1.0	-$2.6	-$2.48	-$5.09
2023	$4,672	$20,996	1.0%	-1.4%	$1.0	-$2.6	-$2.51	-$5.14
2024	$4,671	$20,985	1.0%	-1.4%	$1.0	-$2.7	-$2.53	-$5.18
2025	$4,671	$20,972	1.0%	-1.4%	$1.0	-$2.7	-$2.55	-$5.22
2026	$4,672	$20,960	1.0%	-1.4%	$1.0	-$2.7	-$2.57	-$5.26
2027	$4,672	$20,946	1.0%	-1.4%	$0.6	-$2.3	-$2.59	-$4.86
2028	$4,671	$20,930	1.0%	-1.4%	$0.6	-$2.3	-$2.61	-$4.90
2029	$4,672	$20,981	1.0%	-1.4%	$0.6	-$2.3	-$2.64	-$4.95
2030	$4,671	$20,963	1.0%	-1.4%	$0.6	-$2.3	-$2.66	-$4.99
2031	$4,672	$20,945	1.0%	-1.4%	$0.6	-$2.3	-$2.68	-$5.03
2032	$4,671	$20,925	1.0%	-1.4%	$0.6	-$2.4	-$2.71	-$5.07
2033	$4,671	$20,969	1.0%	-1.4%	$0.6	-$2.4	-$2.74	-$5.13
2034	$4,671	$20,947	1.0%	-1.4%	$0.6	-$2.4	-$2.76	-$5.17
2035	$4,672	$20,925	1.0%	-1.4%	$0.6	-$2.4	-$2.78	-$5.21
2036	$4,671	$20,963	1.0%	-1.4%	$0.6	-$2.5	-$2.81	-$5.27
2037	$4,671	$20,939	1.0%	-1.4%	$0.6	-$2.5	-$2.83	-$5.31
2038	$4,671	$20,974	1.0%	-1.4%	$0.6	-$2.5	-$2.86	-$5.37
2039	$4,671	$20,947	1.0%	-1.4%	$0.6	-$2.5	-$2.88	-$5.41
2040	$4,671	$20,920	1.0%	-1.4%	$0.7	-$2.5	-$2.91	-$5.45
NPV at 3%					$13.6	-$36.2	-$34.4	-$70.6
NPV at 7%					$7.1	-$17.4	-$15.6	-$33.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-25. Impact on C2 Fishing Vessel Market: 800–2,000 hp (Average Price per Vessel = $1,627,500)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Consumer Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2014	$0	-$2	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2015	$0	-$5	0.0%	0.0%	$0.1	-$0.1	Loss less than $0.1	-$0.15
2016	$3,976	$74,266	4.6%	-6.5%	$0.1	-$0.3	-$0.21	-$0.48
2017	$3,974	$74,193	4.6%	-6.5%	$0.1	-$0.2	-$0.21	-$0.46
2018	$3,972	$57,092	3.5%	-5.0%	$0.0	-$0.2	-$0.17	-$0.34
2019	$3,970	$57,033	3.5%	-5.0%	$0.0	-$0.2	-$0.17	-$0.34
2020	$3,967	$56,975	3.5%	-5.0%	$0.0	-$0.2	-$0.17	-$0.35
2021	$3,964	$56,919	3.5%	-4.9%	$0.0	-$0.2	-$0.17	-$0.35
2022	$3,961	$56,861	3.5%	-4.9%	$0.0	-$0.2	-$0.17	-$0.35
2023	$3,958	$56,806	3.5%	-4.9%	$0.0	-$0.2	-$0.17	-$0.35
2024	$3,954	$56,749	3.5%	-4.9%	$0.0	-$0.2	-$0.17	-$0.36
2025	$3,950	$56,694	3.5%	-4.9%	$0.0	-$0.2	-$0.18	-$0.36
2026	$3,977	$56,656	3.5%	-4.9%	$0.0	-$0.2	-$0.18	-$0.36
2027	$3,973	$57,298	3.6%	-5.0%	$0.0	-$0.2	-$0.18	-$0.34
2028	$3,968	$57,238	3.6%	-5.0%	$0.0	-$0.2	-$0.18	-$0.34
2029	$3,962	$57,178	3.6%	-5.0%	$0.0	-$0.2	-$0.18	-$0.35
2030	$3,957	$57,121	3.5%	-5.0%	$0.0	-$0.2	-$0.19	-$0.35
2031	$3,952	$57,064	3.5%	-5.0%	$0.0	-$0.2	-$0.19	-$0.35
2032	$3,975	$57,025	3.5%	-5.0%	$0.0	-$0.2	-$0.19	-$0.35
2033	$3,969	$56,970	3.5%	-5.0%	$0.0	-$0.2	-$0.19	-$0.36
2034	$3,962	$56,915	3.5%	-4.9%	$0.0	-$0.2	-$0.19	-$0.36
2035	$3,956	$56,861	3.5%	-4.9%	$0.0	-$0.2	-$0.19	-$0.36
2036	$3,977	$56,823	3.5%	-4.9%	$0.0	-$0.2	-$0.20	-$0.37
2037	$3,970	$56,771	3.5%	-4.9%	$0.0	-$0.2	-$0.20	-$0.37
2038	$3,962	$56,720	3.5%	-4.9%	$0.0	-$0.2	-$0.20	-$0.37
2039	$3,955	$56,670	3.5%	-4.9%	$0.0	-$0.2	-$0.20	-$0.37
2040	$3,974	$56,634	3.5%	-4.9%	$0.0	-$0.2	-$0.20	-$0.38
NPV at 3%					$0.5	-$2.5	-$2.4	-$4.9
NPV at 7%					$0.3	-$1.2	-$1.1	-$2.3

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7B-26. Impact on C2 Fishing Vessel Market: >2,000 hp (Average Price per Vessel = $3,150,000)[a,b]

Year	Variable Engineering Cost/Unit	Absolute Change in Price ($)	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Equipment Manufacturers' Surplus (million $)	Change in Consumer Surplus (million $)	Change in Total Surplus (million $)
2007	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2008	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2009	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2010	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2011	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2012	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2013	$0	$0	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2014	$0	-$6	0.0%	0.0%	<$0.1	Loss less than $0.1	Loss less than $0.1	Loss less than $0.1
2015	$0	-$12	0.0%	0.0%	$0.6	-$0.6	Loss less than $0.1	-$0.58
2016	$7,154	$116,881	3.7%	-5.2%	$0.4	-$1.5	-$1.34	-$2.86
2017	$7,157	$116,864	3.7%	-5.2%	$0.3	-$1.4	-$1.35	-$2.77
2018	$7,152	$89,954	2.9%	-4.0%	$0.2	-$1.0	-$1.06	-$2.10
2019	$7,154	$89,932	2.9%	-4.0%	$0.2	-$1.0	-$1.07	-$2.11
2020	$7,156	$89,910	2.9%	-4.0%	$0.2	-$1.1	-$1.07	-$2.13
2021	$7,157	$89,888	2.9%	-4.0%	$0.2	-$1.1	-$1.08	-$2.15
2022	$7,158	$89,866	2.9%	-4.0%	$0.2	-$1.1	-$1.09	-$2.17
2023	$7,158	$89,844	2.9%	-4.0%	$0.2	-$1.1	-$1.10	-$2.19
2024	$7,157	$89,822	2.9%	-4.0%	$0.2	-$1.1	-$1.11	-$2.20
2025	$7,156	$89,802	2.9%	-4.0%	$0.2	-$1.1	-$1.12	-$2.22
2026	$7,154	$89,781	2.9%	-4.0%	$0.2	-$1.1	-$1.13	-$2.24
2027	$7,152	$89,760	2.8%	-4.0%	$0.1	-$1.0	-$1.14	-$2.14
2028	$7,157	$89,745	2.8%	-4.0%	$0.1	-$1.0	-$1.15	-$2.16
2029	$7,154	$89,727	2.8%	-4.0%	$0.1	-$1.0	-$1.16	-$2.18
2030	$7,157	$89,714	2.8%	-4.0%	$0.1	-$1.0	-$1.17	-$2.20
2031	$7,153	$89,699	2.8%	-4.0%	$0.1	-$1.0	-$1.18	-$2.22
2032	$7,155	$89,689	2.8%	-4.0%	$0.1	-$1.0	-$1.19	-$2.24
2033	$7,157	$89,680	2.8%	-4.0%	$0.1	-$1.1	-$1.20	-$2.26
2034	$7,151	$89,667	2.8%	-4.0%	$0.1	-$1.1	-$1.22	-$2.28
2035	$7,152	$89,659	2.8%	-4.0%	$0.1	-$1.1	-$1.23	-$2.30
2036	$7,152	$89,651	2.8%	-4.0%	$0.1	-$1.1	-$1.24	-$2.32
2037	$7,152	$89,644	2.8%	-4.0%	$0.1	-$1.1	-$1.25	-$2.34
2038	$7,158	$89,642	2.8%	-4.0%	$0.1	-$1.1	-$1.26	-$2.36
2039	$7,156	$89,637	2.8%	-4.0%	$0.1	-$1.1	-$1.27	-$2.38
2040	$7,154	$89,633	2.8%	-4.0%	$0.1	-$1.1	-$1.28	-$2.40
NPV at 3%					$2.7	-$14.8	-$15.2	-$30.0
NPV at 7%					$1.4	-$7.0	-$6.9	-$13.9

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[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7C: Impacts on Transportation Service Markets

This appendix provides the time series of impacts from 2007 through 2040 for two transportation service markets (railroad and marine). Table 7C-1 through Table 7C-2 provide the time series of impacts and include the following:

- relative change in market price (%)
- relative change in market quantity (%)
- total engineering costs (variable and fixed) associated with each engine market
- changes in service user surplus
- changes in service provider surplus
- changes in total surplus

All costs and surplus changes are presented in 2005 dollars and real service prices are assumed to be constant during the period of analysis. Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 and 2040 time period.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

Table 7C-1. Table 7C-1. Impact on Railroad Transportation Services Market

Year	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Service Consumer Surplus (million $)	Change in Service Provider Surplus (million $)	Change in Total Surplus (million $)
2007	0.0%	0.0%	$0.0	$0.0	$0.0	$0.0
2008	0.1%	0.0%	$58.0	-$31.5	-$26.2	-$57.7
2009	0.0%	0.0%	$34.5	-$18.8	-$15.6	-$34.4
2010	0.1%	0.0%	$55.3	-$30.0	-$25.0	-$55.1
2011	0.1%	-0.1%	$104.8	-$57.0	-$47.5	-$104.4
2012	0.1%	0.0%	$84.0	-$45.6	-$38.0	-$83.6
2013	0.1%	0.0%	$74.4	-$40.4	-$33.7	-$74.1
2014	0.1%	0.0%	$52.6	-$28.6	-$23.8	-$52.4
2015	0.1%	0.0%	$44.0	-$45.9	-$38.2	-$84.1
2016	0.1%	-0.1%	$74.5	-$63.5	-$52.9	-$116.3
2017	0.2%	-0.1%	$72.0	-$75.2	-$62.6	-$137.8
2018	0.2%	-0.1%	$86.5	-$83.8	-$69.8	-$153.6
2019	0.2%	-0.1%	$93.3	-$84.2	-$70.2	-$154.4
2020	0.2%	-0.1%	$81.4	-$78.9	-$65.8	-$144.7
2021	0.2%	-0.1%	$95.7	-$87.9	-$73.2	-$161.1
2022	0.2%	-0.1%	$131.0	-$108.0	-$90.0	-$198.1
2023	0.3%	-0.1%	$189.9	-$140.9	-$117.4	-$258.3
2024	0.3%	-0.1%	$192.1	-$142.6	-$118.8	-$261.4
2025	0.3%	-0.1%	$210.4	-$153.4	-$127.8	-$281.2
2026	0.3%	-0.1%	$210.9	-$154.2	-$128.5	-$282.7
2027	0.3%	-0.2%	$226.1	-$163.1	-$135.9	-$299.0
2028	0.3%	-0.2%	$255.7	-$179.6	-$149.7	-$329.4
2029	0.3%	-0.2%	$271.2	-$188.4	-$157.0	-$345.5
2030	0.4%	-0.2%	$284.5	-$195.9	-$163.2	-$359.1
2031	0.4%	-0.2%	$298.5	-$203.9	-$169.9	-$373.9
2032	0.4%	-0.2%	$308.3	-$209.7	-$174.8	-$384.5
2033	0.4%	-0.2%	$378.4	-$248.0	-$206.6	-$454.6
2034	0.5%	-0.2%	$401.3	-$260.7	-$217.2	-$477.9
2035	0.5%	-0.2%	$422.5	-$272.3	-$227.0	-$499.3
2036	0.5%	-0.2%	$429.0	-$274.6	-$228.9	-$503.5
2037	0.5%	-0.2%	$445.1	-$282.5	-$235.4	-$517.9
2038	0.5%	-0.2%	$460.8	-$290.0	-$241.7	-$531.7
2039	0.5%	-0.2%	$476.4	-$297.4	-$247.8	-$545.2
2040	0.5%	-0.3%	$491.3	-$304.2	-$253.5	-$557.8
NPV at 3%			$3,457.2	-$2,386.5	-$1,988.8	-$4,375.3
NPV at 7%			$1,514.5	-$1,053.7	-$878.1	-$1,931.9

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Table 7C-2. Impact on Marine Transportation Services Market

Year	Change in Price (%)	Change in Quantity (%)	Total Engineering Costs (million $)	Change in Service Consumer Surplus (million $)	Change in Service Provider Surplus (million $)	Change in Total Surplus (million $)
2007	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
2009	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
2011	0.0%	0.0%	$0.0	$0.0	$0.0	$0.0
2012	0.0%	0.0%	$0.0	$0.0	$0.0	$0.0
2013	0.0%	0.0%	$0.0	$0.0	$0.0	$0.0
2014	0.0%	0.0%	$2.8	-$1.5	-$1.3	-$2.8
2015	0.0%	0.0%	$5.6	-$3.1	-$2.5	-$5.6
2016	0.1%	-0.1%	$14.8	-$18.7	-$15.6	-$34.3
2017	0.1%	-0.1%	$23.9	-$23.8	-$19.8	-$43.6
2018	0.2%	-0.1%	$36.0	-$27.9	-$23.3	-$51.2
2019	0.2%	-0.1%	$48.0	-$34.6	-$28.8	-$63.4
2020	0.2%	-0.1%	$60.0	-$41.2	-$34.3	-$75.4
2021	0.3%	-0.1%	$72.0	-$47.7	-$39.8	-$87.5
2022	0.3%	-0.2%	$83.9	-$54.3	-$45.2	-$99.5
2023	0.3%	-0.2%	$95.7	-$60.7	-$50.6	-$111.4
2024	0.4%	-0.2%	$107.5	-$67.2	-$56.0	-$123.2
2025	0.4%	-0.2%	$119.1	-$73.6	-$61.3	-$134.9
2026	0.4%	-0.2%	$130.6	-$79.9	-$66.6	-$146.4
2027	0.5%	-0.2%	$141.9	-$86.1	-$71.8	-$157.9
2028	0.5%	-0.3%	$153.0	-$92.2	-$76.8	-$169.0
2029	0.5%	-0.3%	$163.3	-$97.8	-$81.5	-$179.4
2030	0.6%	-0.3%	$172.6	-$103.0	-$85.8	-$188.8
2031	0.6%	-0.3%	$181.2	-$107.7	-$89.8	-$197.5
2032	0.6%	-0.3%	$189.0	-$112.0	-$93.4	-$205.4
2033	0.6%	-0.3%	$196.4	-$116.1	-$96.8	-$212.9
2034	0.6%	-0.3%	$203.6	-$120.1	-$100.1	-$220.2
2035	0.6%	-0.3%	$210.4	-$123.9	-$103.2	-$227.1
2036	0.6%	-0.3%	$216.9	-$127.5	-$106.2	-$233.7
2037	0.7%	-0.3%	$222.7	-$130.7	-$108.9	-$239.7
2038	0.7%	-0.3%	$227.9	-$133.6	-$111.3	-$244.9
2039	0.7%	-0.3%	$232.4	-$136.1	-$113.5	-$249.6
2040	0.7%	-0.3%	$236.3	-$138.4	-$115.3	-$253.7
NPV at 3%			$1,648.3	-$1,015.4	-$846.2	-$1,861.6
NPV at 7%			$646.4	-$405.9	-$338.2	-$744.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7D: Time Series of Social Costs

This appendix provides a time series of the rule's estimated social costs from 2007 through 2040. Costs are presented in 2005 dollars. In addition, this appendix includes the net present values by stakeholder for 2006 using social discount rates of 3% and 7% over the 2007 and 2040 time period. As a result, it illustrates how the choice of discount rate determines the present value of the total social costs of the program.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

Table 7D-1. Time Series of Social Costs: 2007 to 2040 (Million $)[a,b]

Stakeholder Groups	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Locomotives												
Locomotive producers	–$3.2	–$3.4	–$3.3	–$7.5	–$11.1	–$12.6	–$12.6	–$17.2	–$8.6	–$13.4	–$0.6	–$0.7
Rail transportation service providers	$0.0	–$26.2	–$15.6	–$25.0	–$47.5	–$38.0	–$33.7	–$23.8	–$38.2	–$52.9	–$62.6	–$69.8
Users of rail transportation service	$0.0	–$31.5	–$18.8	–$30.0	–$57.0	–$45.6	–$40.4	–$28.6	–$45.9	–$63.5	–$75.2	–$83.8
Total locomotive sector	–$3.2	–$61.1	–$37.7	–$62.5	–$115.6	–$96.3	–$86.7	–$69.5	–$92.8	–$129.7	–$138.4	–$154.3
Marine												
Marine engine producers	–$25.0	–$25.0	–$25.0	–$25.0	–$86.0	–$41.2	–$41.2	–$41.2	–$56.6	–$0.9	–$0.9	–$0.8
C1 >800 hp	–$1.7	–$1.7	–$1.8	–$1.8	–$22.8	–$20.4	–$20.4	–$20.4	–$26.7	–$0.7	–$0.7	–$0.6
C2 >800 hp	–$4.2	–$4.2	–$4.2	–$4.2	–$27.8	–$20.7	–$20.7	–$20.7	–$29.9	–$0.2	–$0.2	–$0.2
Other marine	–$19.1	–$19.1	–$19.1	–$19.1	–$35.4	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Marine vessel producers	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$17.5	–$18.0	–$14.1	–$9.9
C1 >800 hp	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$12.5	–$13.6	–$10.6	–$7.7
C2 >800 hp	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$5.0	–$4.4	–$3.5	–$2.2
Other marine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Recreational and fishing vessel consumers	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$9.6	–$9.7	–$7.7
Marine transportation service providers	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$1.3	–$2.5	–$15.6	–$19.8	–$23.3
Users of marine transportation service	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$1.5	–$3.1	–$18.7	–$23.8	–$27.9
Total marine sector	–$25.0	–$25.0	–$25.0	–$25.0	–$86.0	–$41.2	–$41.2	–$44.0	–$79.8	–$62.9	–$68.3	–$69.5
Total program	–$28.2	–$86.1	–$62.7	–$87.5	–$201.5	–$137.5	–$127.9	–$113.5	–$172.5	–$192.6	–$206.7	–$223.9

(continued)

Table 7D-1. Time Series of Social Costs: 2007 to 2040 (Million $)[a,b] (continued)

Stakeholder Groups	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Locomotives												
Locomotive producers	–$0.7	–$0.7	–$0.8	–$1.0	–$1.3	–$1.3	–$1.4	–$1.4	–$1.5	–$1.7	–$1.8	–$1.8
Rail transportation service providers	–$70.2	–$65.8	–$73.2	–$90.0	–$117.4	–$118.8	–$127.8	–$128.5	–$135.9	–$149.7	–$157.0	–$163.2
Users of rail transportation service	–$84.2	–$78.9	–$87.9	–$108.0	–$140.9	–$142.6	–$153.4	–$154.2	–$163.1	–$179.6	–$188.4	–$195.9
Total locomotive sector	–$155.1	–$145.3	–$161.9	–$199.0	–$259.6	–$262.7	–$282.6	–$284.1	–$300.6	–$331.0	–$347.2	–$360.9
Marine												
Marine engine producers	–$0.8	–$0.8	–$0.8	–$0.8	–$0.8	–$0.8	–$0.8	–$0.9	–$0.9	–$0.9	–$0.9	–$0.9
C1 >800 hp	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.6	–$0.7
C2 >800 hp	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2
Other marine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Marine vessel producers	–$10.0	–$10.1	–$10.2	–$10.3	–$10.4	–$10.6	–$10.7	–$10.8	–$7.9	–$8.0	–$8.1	–$8.2
C1 >800 hp	–$7.7	–$7.8	–$7.9	–$7.9	–$8.0	–$8.1	–$8.1	–$8.2	–$6.2	–$6.3	–$6.4	–$6.4
C2 >800 hp	–$2.2	–$2.3	–$2.3	–$2.3	–$2.4	–$2.4	–$2.4	–$2.5	–$1.5	–$1.6	–$1.6	–$1.6
Other marine	$0.0	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1	–$0.1
Recreational and fishing vessel consumers	–$7.7	–$7.8	–$7.9	–$7.9	–$8.0	–$8.1	–$8.1	–$8.2	–$8.3	–$8.4	–$8.4	–$8.5
Marine transportation service providers	–$28.8	–$34.3	–$39.8	–$45.2	–$50.6	–$56.0	–$61.3	–$66.6	–$71.8	–$76.8	–$81.5	–$85.8
Users of marine transportation service	–$34.6	–$41.2	–$47.7	–$54.3	–$60.7	–$67.2	–$73.6	–$79.9	–$86.1	–$92.2	–$97.8	–$103.0
Total marine sector	–$81.9	–$94.1	–$106.4	–$118.5	–$130.6	–$142.6	–$154.5	–$166.3	–$174.9	–$186.3	–$196.8	–$206.5
Total program	–$236.9	–$239.5	–$268.2	–$317.6	–$390.2	–$405.4	–$437.2	–$450.4	–$475.5	–$517.3	–$544.0	–$567.3

(continued)

Table 7D-1. Time Series of Social Costs: 2007 to 2040 (Million $)[a,b] (continued)

Stakeholder Groups	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV (3%)	NPV (7%)
Locomotives												
Locomotive producers	–$1.9	–$1.9	–$2.3	–$2.4	–$2.5	–$2.4	–$2.4	–$2.4	–$2.3	–$2.3	–$92.8	–$63.5
Rail transportation service providers	–$169.9	–$174.8	–$206.6	–$217.2	–$227.0	–$228.9	–$235.4	–$241.7	–$247.8	–$253.5	–$1,988.8	–$878.1
Users of rail transportation service	–$203.9	–$209.7	–$248.0	–$260.7	–$272.3	–$274.6	–$282.5	–$290.0	–$297.4	–$304.2	–$2,386.5	–$1,053.7
Total locomotive sector	–$375.8	–$386.4	–$456.9	–$480.3	–$501.8	–$505.9	–$520.3	–$534.1	–$547.6	–$560.1	–$4,468.1	–$1,995.4
Marine												
Marine engine producers	–$0.9	–$0.9	–$1.0	–$1.0	–$1.0	–$1.0	–$1.0	–$1.0	–$1.0	–$1.0	–$313.3	–$242.3
C1 >800 hp	–$0.7	–$0.7	–$0.7	–$0.7	–$0.7	–$0.7	–$0.7	–$0.7	–$0.7	–$0.7	–$102.1	–$73.9
C2 >800 hp	–$0.2	–$0.2	–$0.2	–$0.3	–$0.3	–$0.3	–$0.3	–$0.3	–$0.3	–$0.3	–$112.4	–$84.4
Other marine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	–$98.7	–$84.0
Marine vessel producers	–$8.3	–$8.4	–$8.5	–$8.6	–$8.7	–$8.8	–$8.9	–$9.0	–$9.1	–$9.1	–$143.8	–$71.3
C1 >800 hp	–$6.5	–$6.6	–$6.6	–$6.7	–$6.8	–$6.8	–$6.9	–$7.0	–$7.0	–$7.1	–$110.1	–$54.3
C2 >800 hp	–$1.7	–$1.7	–$1.7	–$1.7	–$1.8	–$1.8	–$1.8	–$1.8	–$1.9	–$1.9	–$32.4	–$16.5
Other marine	–$0.1	–$0.1	–$0.1	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$0.2	–$1.3	–$0.5
Recreational and fishing vessel consumers	–$8.6	–$8.7	–$8.7	–$8.8	–$8.9	–$9.0	–$9.1	–$9.1	–$9.2	–$9.3	–$110.0	–$50.1
Marine transportation service providers	–$89.8	–$93.4	–$96.8	–$100.1	–$103.2	–$106.2	–$108.9	–$111.3	–$113.5	–$115.3	–$846.2	–$338.2
Users of marine transportation service	–$107.7	–$112.0	–$116.1	–$120.1	–$123.9	–$127.5	–$130.7	–$133.6	–$136.1	–$138.4	–$1,015.4	–$405.9
Total marine sector	–$215.3	–$223.4	–$231.1	–$238.5	–$245.6	–$252.5	–$258.6	–$264.1	–$268.9	–$273.1	–$2,428.7	–$1,107.7
Total program	–$591.1	–$609.8	–$688.0	–$718.8	–$747.4	–$758.3	–$778.8	–$798.1	–$816.4	–$833.2	–$6,896.8	–$3,103.1

[a] Figures are in 2005 dollars.

[b] Net present values for 2006 are calculated using a social discount rate of 3% and 7% over the 2007 to 2040 time period.

Appendix 7E: Model Equations

To develop the economic impact model, we use a set of nonlinear supply and demand equations for the affected markets and transform them into a set of linear supply and demand equations. These resulting equations describe stakeholder production and consumption responses to policy-induced cost and price changes in each market. They are also used to specify the conditions for a new with-policy equilibrium. We describe these equations in more detail below.

7E.1 Economic Model Equations

7E.1.1 Supply Equations

First, we consider the formal definition of the elasticity of supply with respect to changes in own price:

$$\varepsilon_s = \frac{dQ_s / Q_s}{dp / p}. \tag{7E.1}$$

Next, we can use "hat" notation to transform Eq. (7E.1) to proportional changes and rearrange terms:

$$\hat{Q}_s = \varepsilon_s \hat{p} \tag{7E.1a}$$

where

$\hat{Q}_s$ = percentage change in the quantity of market supply,

ε_s = market elasticity of supply, and

$\hat{p}$ = percentage change in market price.

As Fullerton and Metcalfe (2002) note, this approach takes the elasticity definition and turns it into a linear *behavioral* equation for each market.

To introduce the direct impact of the regulatory program, we assume the direct per-unit compliance cost (c) leads to a proportional shift in the marginal cost of production. Under the assumption of perfect competition (price equals marginal cost), we can approximate this shift at the initial equilibrium point as follows:

$$\hat{MC} = \frac{c}{MC_o} = \frac{c}{p_o}. \tag{7E.1b}$$

The with-regulation supply response to price and cost changes can now be written as:

$$\hat{Q}_S = \varepsilon_S \left(\hat{p} - \hat{M}C \right) \qquad (7E.1c)$$

For equipment producers, the supply response also simultaneously accounts for changes in equilibrium input prices (engines). To do this, we modify Eq. (7E.1b) as follows:

$$\hat{M}C = \frac{c + \alpha(\Delta p_{eng})}{MC_o} = \frac{c + \alpha(\Delta p_{eng})}{p_o} \qquad (7E.1d)$$

where Δp_{engine} is the equilibrium change in the engine price and α is the ratio of engines used per unit of equipment. For example, if one piece of equipment uses only one engine, then $\alpha = 1$. This equation can accommodate other input-output ratios by multiplying Δp_{eng} by the appropriate input-to-output ratio (α).

For transportation service providers, the supply response also simultaneously accounts for changes in equilibrium input prices (equipment). To do this, we use an equation similar to Eq. (7E.1.d):

$$\hat{M}C = \frac{c + \alpha(\Delta p_{equip})}{MC_o} = \frac{c + \alpha(\Delta p_{equip})}{p_o} \qquad (7E.1e)$$

where Δp_{equip} is the equilibrium change in the equipment price and α is the ratio of equipment used per unit of transportation services.

7E.1.2 Demand Equations

Similar to supply, we can characterize services and selected equipment[18] demand responses to price changes as:

$$\hat{Q}_d = \eta_d \hat{p} \qquad (7E.2)$$

where

$\hat{Q}_d$ = percentage change in the quantity of market demand,

η^d = market elasticity of demand, and

$\hat{p}$ = percentage change in market price.

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[18] The equipment markets are recreational vessels and fishing vessels. The remaining vessel and locomotive demand curves are derived from the supply decisions of the appropriate downstream transportation service markets.

In contrast the demand for engines and selected equipment markets is a derived demand and is related to equipment or service supply decisions. In order to maintain a constant input-to-output ratio, the derived demand for inputs is specified as:

$$\hat{Q}_{input} = \hat{Q}_{output} . \tag{7E.3}$$

7E.1.3 Market Equilibrium Conditions

In response to the exogenous increase production costs, stakeholder responses are completely characterized by represented in Eq. (7E.1.c)(service, equipment and engine supply), Eq. (7E.2) (service and selected equipment demand), Eq. (7E.3) (derived demand for selected equipment and engine). Next, we specify the relationship that must hold for markets to "clear", that is, supply in each market equals demand. Given the equations specified above, the new equilibrium satisfies the condition that for each market, the proportional change in supply equals the proportional change in demand:

$$\hat{Q}_s = \hat{Q}_d . \tag{7E.4}$$

7E.2 Computing With-Regulation Equilibrium Conditions within the Spreadsheet

The French economist Léon Walras proposed one early model of market price adjustment by using the following thought experiment. Suppose there is a hypothetical agent that facilitates market adjustment by playing the role of an "auctioneer." He announces prices, collects information about supply and demand responses (without transactions actually taking place), and continues this process until market equilibrium is achieved.

For example, consider the with-regulation supply and demand conditions at the without-regulation equilibrium price (P) (see Figure 7E-1). The auctioneer determines that the quantity demanded (A) exceeds the quantity supplied (B) at this price and calls out a new (higher) price (P′) based on the amount of excess demand. Consumers and producers make new consumption and production choices at this new price (i.e., they move along their respective demand and supply functions), and the auctioneer checks again to see if excess demand or supply exists. This process continues until P = P* (point C in Figure 7E-1) is reached (i.e., excess demand is zero in the market). A similar analysis takes place when excess supply exists. The auctioneer calls out lower prices when the price is higher than the equilibrium price.

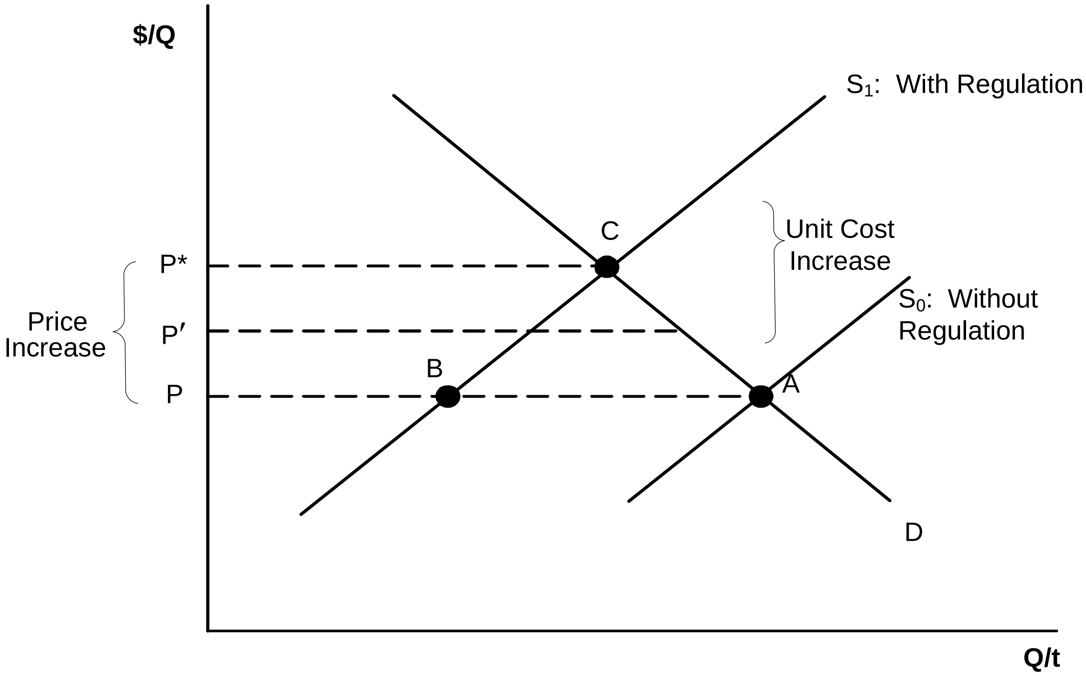


Figure 7E-1. Computing With-Regulation Equilibrium

The economic model uses a similar type of algorithm for determining with-regulation equilibria, and the process 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 the 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:

$$P_{i+1} = P_1 \bullet \left(\frac{q_d}{q_s} \right)^z \tag{7E.5}$$

4. Recalculate market supply with new 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.

7E.3 Social Costs: Consumer and Producer Economic Welfare Calculations

The change in consumer surplus in the affected markets can be estimated using the following linear approximation method:

$$\Delta CS = -[Q_1 \times \Delta p] + [0.5 \times \Delta Q \times \Delta p]. \qquad (7E.6)$$

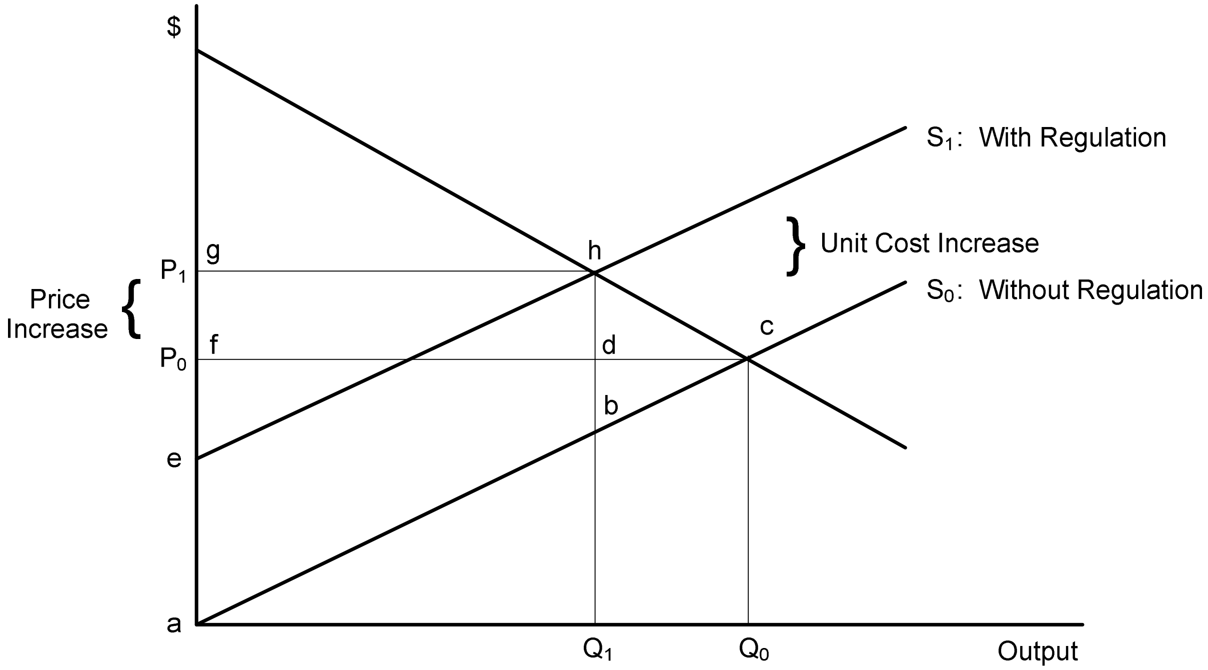
As shown, higher market prices and reduced consumption lead to welfare losses for consumers. A geometric representation of this calculation is illustrated in Figure 7E-2.

For affected supply, the change in producer surplus can be estimated with the following equation:

$$\Delta PS = [Q_1 \times \Delta p] - [Q_1 \times \Delta MC] - [0.5 \times \Delta Q \times (\Delta p - \Delta MC)]. \qquad (7E.7)$$

Increased regulatory costs and output declines have a negative effect on producer surplus, because the net price change ($\Delta p - \Delta MC$) is negative. However, these losses are mitigated, to some degree, as a result of higher market prices. A geometric representation of this calculation is also illustrated in Figure 7E-2.

Throughout this report, changes in surplus reflect the *social costs* of the proposed rule. These calculations exclude any environmental benefits associated with the proposed rule.



Δ consumer surplus = –[fghd + dhc]

Δ producer surplus = [fghd – aehb] – bdc

Δ total surplus = –[aehb + dhc + bdc]

Figure 7E-2. Economic Welfare Calculations: Changes in Consumer, Producer, and Total Surplus

Appendix 7F: Elasticity Parameters for Economic Impact Modeling

Elasticities were obtained from peer-reviewed literature or were obtained from other sources that estimated these parameters using empirical methods (i.e. econometrically). Table 7F-1 and Table 7F-2 summarize the price elasticities of supply and demand used in this anlaysis. The methodologies for estimating the supply and demand elasticities are described in the documents identified in the data source column. The unknown parameters for the analysis were the locomotive and commercial marine vessel supply elasticities and this appendix describes the methods and data used to identify an acceptable value for the economic impact analysis.

It should be noted that the methods we used to estimate the price elasticites described below have certain limitations. The production function approach that was used to estimate several of the supply elasticities was used due to limitations in available data. Specifically, firm level or plant level data was unavailable for the companies that operate in the affected sectors. As a result, several of the supply elasticities were estimated using a production function approach with industry level aggregate data. However, the use of aggregate industry level data may not be appropriate or an accurate way to estimate the price elasticity of supply compared to firm-level or plant-level data. This is because, at the aggregate industry level, the size of the data sample is limited to the time series of the available years and because aggregate industry data may not reveal each individual firm or plant production function (heterogeneity). There may be significant differences among the firms that may be hidden in the aggregate data but that may affect the estimated elasticity. In addition, the use of time series aggregate industry data may introduce time trend effects that are difficult to isolate and control.

To address these concerns, EPA intends to investigate estimates for the price elasticity of supply for the affected industries for which published estimates are not available, using alternative methods and data inputs. This research program will use the cross-sectional data model at either the firm-level or plant level from the U.S. Census Bureau to estimate these elasticities. We plan to use the results of this research provided the results are robust and that they are available in time for the analysis for the final rule.

Table 7F-1. Summary of Market Demand Elasticities Used in EIM

MARKET	ESTIMATE	SOURCE	METHOD	DATA SOURCE
Rail				
Rail Transp. Svcs	-0.5	Literature Estimate	Literature Review	Boyer, K.D. 1997. *Principles of Transportation Economics*. Reading, MA: Addison-Wesley.
Locomotives	Derived			

MARKET	ESTIMATE	SOURCE	METHOD	DATA SOURCE
Marine				
Marine Transp. Svcs	-0.5	Literature Estimate	Assumed value	Uses the same elasticity as the locomotive transportation services sector.
Vessels—Commercial	Derived			
Vessels—Fishing	-1.4	Econometric Estimate	Assumed value	Uses the same elasticity as the recreation vessels sector.
Vessels—Recreational	-1.4	Econometric Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2002. *Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines*. EPA420-R-02-022. Available at <http://www.epa.gov/otaq/regs/nonroad/2002/r02022.pdf>.
Engines	Derived			

Table 7F-2. Summary of Supply Elasticities Used in EIM

MARKET	ESTIMATE	SOURCE	METHOD	DATA SOURCE
Rail				
Rail Transp. Svcs	0.6	Literature Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Available at <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>.
Locomotives	2.7	EPA Estimate	Calibration Method	U.S. Bureau of the Census. 2004. "Railroad Rolling Stock Manufacturing: 2002." *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336510 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. "Statistics for Industry Groups and Industries: 2004." *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Marine				
Marine Transp. Svcs	0.6	Literature Estimate	Assumed value	Uses the same elasticity as the rail transportation services sector.

Vessels—Commercial	2.3	EPA Estimate	Calibration Method	U.S. Bureau of the Census. 2004. “Ship Building and Repairing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336611 (RV). Washington, DC: U.S. Bureau of the Census. Table 1. U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004.” *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.
Vessels—Fishing	1.6	Econometric Estimate	Assumed value	Uses the same elasticity as the recreation vessels sector.
Vessels—Recreational	1.6	Econometric Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2002. *Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines*. EPA420-R-02-022. Available at <http://www.epa.gov/otaq/regs/nonroad/2002/r02022.pdf>.
Engines	3.8	Econometric Estimate	Previous EPA Economic Analysis	U.S. Environmental Protection Agency (EPA). 2004. *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*. EPA420-R-04-007. Available at <http://www.epa.gov/nonroad-diesel/2004fr/420r04007.pdf>.

The technique we used to quantify the locomotive and commercial marine vessel industry supply elasticity involves specifying an economic model of supply, treating some of the parameters of the model as fixed using secondary data, and solving for unknown parameters that replicate a benchmark data set.[19] The specific procedure uses an analytical expression for a short-to-intermediate run supply elasticity derived by Rutherford and recent benchmark data sets from Economic Census data between 1997 and 2004. [22] The industry-level benchmark data set offers advantages over previously used data sets (e.g., National Bureau of Economic Research [NBER] Manufacturing Productivity Database) because it relies on the latest industrial classification system (North American Industry Classification System [NAICS]). Using the latest classification system allows us to select a more precise industry code that characterizes locomotive manufacturing. In addition, EPA can use the most up-to-date data set available for the analysis.

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[19] A complete discussion of the meaning, merits and criticism, and best practices of these types of techniques can be found in Dawkins, Christina & T. N. Srinivasan, & John Whalley, (2001). “Calibration” in Handbook of Econometrics, Volume 5, ed. J. J. Heckman & E. E. Leamer, (Amsterdam: Elsevier).

As described by Rutherford, the procedure specifies that the functional form of the production function is the constant elasticity of substitution (CES). It also assumes there is a fixed capital input that makes it consistent with the intermediate-run time frame of the analysis. As Rutherford shows, the price elasticity of supply can be expressed as

$$\varepsilon = (1 - \theta) \times \sigma / \theta,$$

where θ represents the value share of capital and σ represents the elasticity of substitution between inputs. For this analysis, we assume an elasticity of substitution of one ($\sigma = 1$), which yields a Cobb-Douglas production technology that is a special case of the CES production function. The Cobb-Douglas production function is one of the most commonly used production functions in economics studies.

We collected the latest Economic Census data for NAICS 336510 (Railroad Rolling Stock Manufacturing) that provides an estimate of the value share of capital θ for locomotives. To compute this value share, we subtracted reported payroll costs from the reported industry value added and divided by the total value of shipments (see Table 7F-3). Using the elasticity formula, $\sigma = 1$, and annual value share data reported in Table 7F-3, we computed an average supply elasticity value of 2.7 for this industry. Accounting for variability of the value share parameter across 1997 to 2004, we computed a 95% confidence interval for the elasticity value that ranges from 1.9 to 3.4.

Similarly, we estimated the value share of capital θ for commercial marine vessels from latest Economic Census data for NAICS 336611 (Ship Building and Repairing Manufacturing). Using the elasticity formula, $\sigma = 1$, and annual value share data reported in Table 7F-4, we computed an average supply elasticity value of 2.3 for this industry. By the value share parameter across 1997 to 2004, we computed a 95% confidence interval for the elasticity value that ranges from 1.3 to 3.2.

The parameter estimates suggest both locomotive and commercial marine vessel supplies are elastic and firms can change production levels in response to changes in market prices. Two factors support an elastic supply estimate for this sector. First, industries that are less capital intensive typically have more flexibility to adjust variable inputs (e.g. labor and/or materials) and can change production levels in response to variations in market prices. The Census data for locomotive and ship building manufacturing are consistent with this observation and suggest the capital share of production costs in the locomotive or ship building industry is small relative to other inputs. The value share of capital is ranging from 20% to 30% for locomotives and from 25% to 38% for ship building and repairing. Second, industries with excess production capacity also have more flexibility to change output levels in response to price changes. Data from the Census also suggest the locomotive manufacturing industry's capacity utilization rates have been low, implying excess capacity exists. Data for the fourth quarters of 2000 to 2004 show utilization rates ranging from 45% to 69%. For ship building and repairing industry, the production capacity utilization ratio for the fourth quarters of 2000 to 2004 is ranging around 50% to 80% according to U.S. Bureau of the Census data.

Table 7F-3. Benchmark Supply Elasticities for NAICS 336510 (Railroad Rolling Stock Manufacturing): 1997–2004 ($1,000)

					Supply Elasticity $\varepsilon = (1 - \theta) \times \sigma / \theta$
Year	**Value of Shipments**	**Value Added**	**Payroll Costs**	**Value Share of Capital (θ)[a]**	**$\sigma=1$ (Cobb-Douglas)**
2004	$7,566,129	$3,216,704	$1,123,054	28%	2.6
2003	$7,404,763	$2,909,834	$1,156,084	24%	3.2
2002	$7,793,382	$3,741,703	$1,195,073	33%	2.1
2001	$8,578,053	$3,824,449	$1,449,784	28%	2.6
2000	$9,722,424	$4,360,089	$1,480,181	30%	2.4
1999	$10,352,310	$4,460,735	$1,532,969	28%	2.5
1998	$9,256,810	$3,848,408	$1,440,110	26%	2.8
1997	$8,263,395	$3,345,283	$1,319,135	25%	3.1
Parameter Statistics					
Average					2.7
Standard deviation					0.4
Upper bound (95% confidence interval)					3.4
Lower bound (95% confidence interval)					1.9

[a] The value share of capital is computed by subtracting payroll costs from reported value added and dividing by the total value of shipments.

Sources: U.S. Bureau of the Census. 2004. “Railroad Rolling Stock Manufacturing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336510 (RV). Washington, DC: U.S. Bureau of the Census. Table 1.

U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004.” *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.

Table 7F-4. Benchmark Supply Elasticities for NAICS 336611 (Ship Building & Repairing): 1997–2004 ($1,000)

Year	Value of Shipments	Value Added	Payroll Costs	Value Share of Capital (θ)[a]	Supply Elasticity $\varepsilon = (1 - \theta) \times \sigma / \theta$
					$\sigma=1$ (Cobb-Douglas)
2004	$13,705,958	$8,573,286	$3,772,590	35%	1.9
2003	$13,485,503	$8,679,730	$3,692,026	37%	1.7
2002	$12,814,574	$8,449,010	$3,628,382	38%	1.7
2001	$11,792,832	$6,968,749	$3,439,474	30%	2.3
2000	$11,380,112	$6,324,192	$3,435,806	25%	2.9
1999	$11,070,960	$6,328,784	$3,336,632	27%	2.7
1998	$11,143,246	$6,728,975	$3,347,525	30%	2.3
1997	$10,542,961	$6,202,797	$3,353,414	27%	2.7
Parameter Statistics					
Average					2.3
Standard Deviation					0.5
Upper Bound (95% Confidence Interval)					3.2
Lower Bound (95% Confidence Interval)					1.3

[a] The value share of capital is computed by subtracting payroll costs from reported value added and dividing by the total value of shipments.

Sources: U.S. Bureau of the Census. 2004b. “Ship Building and Repairing: 2002.” *2002 Economic Census Manufacturing Industry Series*. EC02-31I-336611 (RV). Washington, DC: U.S. Bureau of the Census. Table 1.

U.S. Bureau of the Census. 2005. “Statistics for Industry Groups and Industries: 2004.” *Annual Survey of Manufacturers.* M04(AS)-1. Washington, DC: U.S. Bureau of the Census. Table 2.

Appendix 13G: Initial Market Equilibrium - Price Forecasts

The EIM analysis begins with current market conditions: equilibrium supply and demand. To estimate the economic impact of a regulation, standard practice uses projected market equilibrium (time series of prices and quantities) as the baseline and evaluates market changes from this projected baseline. Consequently, it is necessary to forecast equilibrium prices and quantities for future years.

Equilibrium price forecasts typically use one of two approaches (EPA 1999, p 5-25). The first assumes a constant (real) price of goods and services over time. The second models a specific time series where prices may change over time due to exogenous factors.

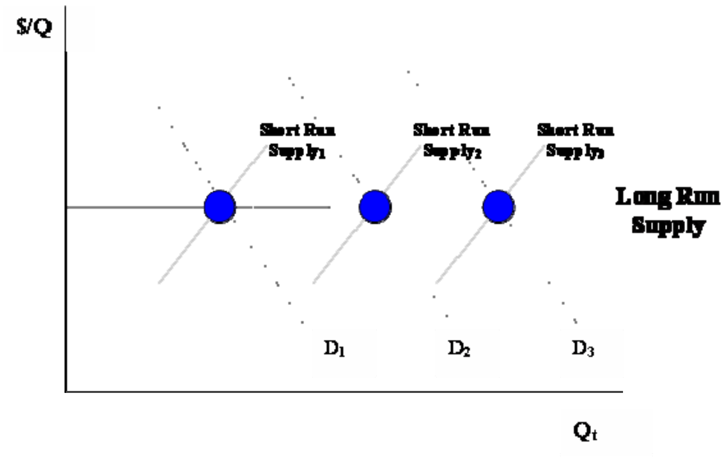

Figure 13.3-1. Prices and Quantities in Long Run Market Equilibrium

In the absence of shocks to the economy or the supply of raw materials, economic theory suggests that the equilibrium market price for goods and services should remain constant over time. As shown in Figure 7G-1, demand grows over time, in the long run, capacity will also grow as existing firms expand or new firms enter the market and eliminate any excess profits. This produces a flat long run supply curve. Note that in the short to medium run time frame the supply curve has a positive slope due to limitations in how quickly firms can react.

If capacity is constrained (preventing the outward shift of the baseline supply curve) or if the price of production inputs increase (shifting the baseline supply curve upward over time), then prices may trend upward reflecting that either the growth in demand is exceeding supply or the commodity is becoming more expensive to produce.

It is very difficult to develop forecasts events (such as those mentioned above) that influence long run prices. As a result, the approach used in this analysis is to use a constant 2005 observed price.

Appendix 7H: Sensitivity Analysis

The economic impact analysis presented in this Chapter is based on an economic impact model developed specifically for this analysis. The EIM reflects specific assumptions about behavioral responses (modeled by supply and demand elasticities) and how the engineering compliance costs are included in the market supply function shift. This appendix examines the sensitivity of the results to the values used for these key parameters. Alternative values for these parameters are selected and the results are compared to the results of the primary analysis described in Section 7.1. Three model components are examined:

- Scenario 1: alternative market supply and demand elasticity parameters
- Scenario 2: alternative ways to treat the market supply shifts
- Scenario 3: alternative ways to treat marine operating costs

The results of these sensitivity analyses are presented below. Although estimates of total economic welfare changes are similar for many of the scenarios, the different assumptions highlight the role the assumptions play in determining the distribution of welfare changes among stakeholders.

The NPV calculations presented in this Appendix are based on the period 2006-2040, reflecting the period when the analysis was completed. This has the consequence of discounting the current year costs, 2007, and all subsequent years are discounted by an additional year. The result is a smaller stream of social costs than by calculating the NPV over 2007-2040 (3% smaller for 3% NPV and 7% smaller for 7% NPV).

7H.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 EIM are discussed in Appendix 10F. 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.

There are at least two ways to examine the sensitivity of the EIA results to assumptions about the price elasticity of supply or demand. The first is to choose upper and lower bounds for these variables based on the ranges of values reported in the literature or based on sensitivity analysis constructed around estimated values. This method was not available for this study because, as described in Appendix F, many of these parameters were obtained from secondary sources and information was not readily available to compute confidence intervals for them. Therefore, an alternative approach was used in which the supply or demand elasticity parameters were increased/decreased by 25 percent while holding the other elasticities constant. Table 7H-1 reports the upper- and lower-bound demand and supply elasticity estimates used in this analysis.

Parameter	Elasticity Source	Lower Bound	Base Case	Upper Bound
DEMAND ELASTICITIES				
Rail and marine transportation services	Literature estimate	-0.4	-0.5	-0.6
Locomotive	Derived		N/A	
Commercial vessels	Derived		N/A	
Recreational and fishing vessels	Econometric Estimate	-1.1	-1.4	-1.8
Marine engines	Derived		N/A	
SUPPLY ELASTICITIES				
Rail and marine transportation services	Literature estimate	0.45	0.6	0.8
Locomotives	Calibration Estimate	2.0	2.7	3.4
Commercial marine vessels	Calibration Estimate	2.0	2.3	3.4
Recreational and fishing vessels	Econometric Estimate	1.2	1.6	2.0
Marine engines	Econometric Estimate	2.9	3.8	4.8

The results of this analysis for 2020 are presented in Tables 7F-2 and 7F-3. Varying the model’s elasticity parameters does not significantly change the estimated impacts on total economic welfare. However, varying the model parameters has an impact on how the regulatory program costs are distributed across stakeholders. The elasticity parameters play an important role in determining the economic incidence of the regulatory program.

In scenarios in which the supply side of the service markets is more responsive to price changes (more elastic) users of services would bear more of the burden of the regulatory program. Thus, when the elasticity of supply is more elastic (producers are more sensitive to a change in price) and demand is held constant, the expected surplus loss to users of transportation services increases from 17 percent to 21 percent for marine and from 33 percent to 36 percent for rail, respectively (see Table 7H-2). Similarly, when the elasticity of demand is less elastic (consumers are less sensitive to a change in price) and the supply elasticity is held constant, the expected surplus loss to users of transportation services increases from 17 percent to 19 percent for marine and from 33 percent to 37 percent for rail, respectively (see Table 7H-3).

In contrast, when the supply side of the service market is less responsive to price changes (the elasticity of supply is less elastic) or the demand side of the service is more sensitive to price changes (the elasticity of demand is more elastic), service providers would bear more of the burden of the regulatory program. Here, when the elasticity of supply is decreased but the elasticity of demand is held constant, the expected surplus loss to providers of transportation services increases from 14 percent to 18 percent for marine and from 28 percent to 32 percent for rail, respectively (see Table 7H-2). When the elasticity of demand is more elastic (consumers are more sensitive to a change in price) and the supply elasticity is held constant, the expected surplus loss to providers of transportation services increases from 14 percent to 16 percent for marine and from 28 percent to 31 percent for rail, respectively (see Table 7H-3).

With regard to locomotive, marine vessel, and marine diesel engine suppliers, their share of the surplus loss increases when the price elasticity of supply is less elastic (they are less sensitive to prices changes) or when the price elasticity of demand is more elastic (consumers are more sensitive to price changes).

With regard to market effects, price increases and quantity decreases are somewhat higher when the price elasticity of supply is more elastic or the price elasticity of demand is less elastic, and somewhat lower when the price elasticity of supply is less elastic or the price elasticity of demand is more elastic.

Table 7H-2. Sensitivity Analysis for Supply Elasticity Parameters: 2020[a]

Market–Level Impacts	Variable Engineering Cost Per Unit	Primary Case				Supply Upper				Supply Lower			
		Change in Price		Change in Quantity		Change in Price		Change in Quantity		Change in Price		Change in Quantity	
		Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Locomotives													
Locomotives	$48,610	$48,092	2.54%	0	–0.08%	$48,177	2.54%	0	–0.08%	$48,041	2.53%	0	–0.06%
Transportation services	NA	NA	0.16%	NA	–0.08%	NA	0.16%	NA	–0.08%	NA	0.13%	NA	–0.06%
Marine													
Engines													
C1 >800 hp	$13,882	$13,269	8.42%	–6	–1.35%	$13,620	8.63%	–3	–0.71%	$13,542	8.63%	–2	–0.56%
C2 >800 hp	$49,379	$48,818	18.7%	–1	–0.72%	$48,683	18.70%	–1	–1.10%	$48,475	18.63%	–1	–0.86%
Other marine	$0	$0	0.00%	0	0.00%	–$5	–0.02%	–3	–0.11%	–$6	–0.03%	–2	–0.09%
Equipment													
C1 >800 hp	$2,979	$16,331	1.14%	–7	–1.35%	$22,965	1.14%	–4	–0.71%	$21,279	1.05%	–3	–0.56%
C2 >800 hp	$6,516	$143,933	3.64%	–1	–0.71%	$141,157	3.69%	–1	–1.10%	$136,129	3.53%	–1	–0.85%
Other marine	$0	–$2	0.00%	–1	0.00%	–$42	–0.02%	–18	–0.05%	–$54	–0.02%	–14	–0.04%
Transportation services	NA	NA	0.24%	NA	–0.12%	NA	1.10%	NA	–0.55%	NA	0.86%	NA	–0.43%
Welfare Impacts (Million $)		**Surplus Change**		**Share**		**Surplus Change**		**Share**		**Surplus Change**		**Share**	
Locomotives													
Locomotive producers		–$0.7		0.3%		–$0.6		0.2%		–$0.7		0.3%	
Rail transportation service providers		–$65.8		27.5%		–$57.9		24.3%		–$76.1		31.9%	
Users of rail transportation service		–$78.9		32.9%		–$86.9		36.4%		–$68.5		28.7%	
Total locomotive sector		–$145.3		60.7%		–$145.3		61.0%		–$145.4		61.0%	
Marine													
Marine engine producers		–$0.8		0.3%		–$0.7		0.3%		–$0.9		0.4%	
C1 >800 hp		–$0.6		0.2%		–$0.3		0.1%		–$0.3		0.1%	
C2 >800 hp		–$0.2		0.1%		–$0.2		0.1%		–$0.3		0.1%	
Other marine		$0.0		0.0%		–$0.2		0.1%		–$0.3		0.1%	
Marine vessel producers		–$10.1		4.2%		–$8.5		3.6%		–$10.1		4.2%	
C1 >800 hp		–$7.8		3.3%		–$4.7		2.0%		–$5.5		2.3%	
C2 >800 hp		–$2.3		0.9%		–$2.5		1.1%		–$3.0		1.2%	
Other marine		–$0.1		0.0%		–$1.3		0.5%		–$1.6		0.7%	
Rec/fishing vessel consumers		–$7.8		3.3%		–$2.4		1.0%		–$1.9		0.8%	
Marine transportation service providers		–$34.3		14.3%		–$32.6		13.7%		–$42.2		17.7%	
Users of marine transportation service		–$41.2		17.2%		–$48.8		20.5%		–$38.0		15.9%	
Total marine sector		–$94.1		39.3%		–$93.0		39.0%		–$93.1		39.0%	
Total program		–$239.5		100.0%		–$238.3		100.0%		–$238.4		100.0%	

[a] Figures are in 2005 dollars.

Table 7H-3. Sensitivity Analysis for Demand Elasticity Parameters: 2020[a]

		Primary Case				Demand Upper Bound				Demand Lower Bound			
		Change in Price		Change in Quantity		Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Variable Engineering Cost Per Unit**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives													
Locomotives	$48,610	$48,092	2.54%	0	–0.08%	$48,058	2.53%	0	–0.08%	$48,193	2.54%	0	–0.06%
Transportation services	NA	NA	0.16%	NA	–0.08%	NA	0.13%	NA	–0.08%	NA	0.17%	NA	–0.06%
Marine													
Engines													
C1 >800 hp	$13,882	$13,269	8.42%	–6	–1.35%	$13,552	8.59%	–3	–0.72%	$13,629	8.64%	–2	–0.55%
C2 >800 hp	$49,379	$48,818	18.74%	–1	–0.72%	$48,501	18.64%	–1	–1.11%	$48,709	18.71%	–1	–0.85%
Other marine	$0	$0	0.03%	0	0.00%	–$6	–0.03%	–3	–0.11%	–$4	–0.02%	–2	–0.08%
Equipment													
C1 >800 hp	$2,979	$16,331	1.14%	–7	–1.35%	$21,492	1.06%	–4	–0.72%	$23,174	1.15%	–3	–0.55%
C2 >800 hp	$6,516	$143,933	3.64%	–1	–0.71%	$136,763	3.55%	–1	–1.11%	$141,778	3.71%	–1	–0.84%
Other marine	$0	–$2	0.02%	–1	0.00%	–$52	–0.02%	–18	–0.05%	–$40	–0.02%	–14	–0.04%
Transportation services	NA	NA	0.24%	NA	–0.12%	NA	0.89%	NA	–0.55%	NA	1.13%	NA	–0.42%
Welfare Impacts (Million $)		**Surplus Change**		**Share**		**Surplus Change**		**Share**		**Surplus Change**		**Share**	
Locomotives													
Locomotive producers			–$0.7	0.3%			–$0.8	0.3%			–$0.6	0.2%	
Rail transportation service providers			–$65.8	27.5%			–$73.8	30.8%			–$55.7	23.2%	
Users of rail transportation service			–$78.9	32.9%			–$70.8	29.6%			–$89.1	37.2%	
Total locomotive sector			–$145.3	60.7%			–$145.3	60.7%			–$145.4	60.7%	
Marine													
Marine engine producers			–$0.8	0.3%			–$0.9	0.4%			–$0.7	0.3%	
C1 >800 hp			–$0.6	0.2%			–$0.7	0.3%			–$0.5	0.2%	
C2 >800 hp			–$0.2	0.1%			–$0.2	0.1%			–$0.2	0.1%	
Other marine			$0.0	0.0%			$0.0	0.0%			–$0.0	0.0%	
Marine vessel producers			–$10.1	4.2%			–$10.9	4.6%			–$9.1	3.8%	
C1 >800 hp			–$7.8	3.3%			–$8.5	3.5%			–$7.0	2.9%	
C2 >800 hp			–$2.3	0.9%			–$2.4	1.0%			–$2.1	0.9%	
Other marine			–$0.1	0.0%			–$0.1	0.0%			$0.0	0.0%	
Rec/fishing vessel consumers			–$7.8	3.3%			–$6.9	2.9%			–$8.9	3.7%	
Marine transportation service providers			–$34.3	14.3%			–$38.5	16.1%			–$29.1	12.1%	
Users of marine transportation service			–$41.2	17.2%			–$36.9	15.4%			–$46.5	19.4%	
Total marine sector			–$94.1	39.3%			–$94.1	39.3%			–$94.2	39.3%	
Total program			–$239.5	100.0%			–$239.4	100.0%			–$239.5	100.0%	

[a] Figures are in 2005 dollars.

7H.2 Fixed Cost Shift Scenario

As discussed in 7.2.3.4, in the primary economic analysis only the variable costs are used to shift the supply curve in the engine and equipment markets. This is because in a competitive market the industry supply curve is generally based on the market's marginal cost curve and fixed costs do not influence production decisions on the margin. In this scenario, the supply shift for engine and equipment producers includes both variable compliance costs and the fixed costs incurred in that year. This would allow the manufacturers to cover the fixed costs that occur in that year.

We present the results of this analysis for 2011 and 2015. In 2011, locomotive manufacturers would be incurring fixed costs associated with the Tier 3 and Tier 4 PM standards; marine engine manufacturers would be incurring costs in connection with both the Tier 3 and Tier 4 standards. Therefore, 2011 is a high-cost year for the program. In 2015, locomotive manufacturers would be incurring fixed costs for Tier 4 NO_x standards; marine engine manufacturers would be incurring costs for the Tier 4 standards. In addition the vessel redesign costs begin in 2015. Both 2011 and 2015 costs are also expected to be elevated due to certification costs.

The results of this analysis are presented in Tables 7H-4 and 7H-5.

In 2011, the changes in the results are considerable. In the market analysis, the expected price change for locomotives increases from -$425 to $11,700, although this is a small increase on a percentage basis (less than 1 percent). The prices of commercial marine engines and commercial marine vessels change significantly. The engine price increases increase from zero percent to 17 percent and 40 percent for commercial C1 and C2 engines, and from zero percent to 2.0 and 7.2 percent for commercial C1 and C2 vessels.

With regard to the social welfare analysis in 2011, the share of the surplus loss borne by locomotive and marine diesel engine producers decreases, while the share borne by rail and marine transportation service providers and users, as well as marine vessel suppliers, increases. This is because the fixed costs are passed from the producers to the end users. The share of the surplus loss decreases from 5.5 percent to 0.2 percent for locomotive producers and from 42.7 percent to 1.5 percent for marine engine producers, and increases from zero percent to 12.4 percent for marine vessel producers. The share increases from 23.6 percent and 28.3 percent to 26.1 percent and 31.3 percent for rail transportation service providers and users, and from zero percent to 6.5 percent and 7.8 percent for marine transportation service providers and users.

The impacts the 2015 results, for the Tier 4 program, are similar with large changes in the expected price increases and a shift from the engine and locomotive suppliers to the vessel suppliers and transportation service markets. In this case, however, there is a larger shift to the marine transportation service market, with the vessel suppliers bearing less of the costs. Specifically, the engine producer share is only about one percent in this case, with the marine transportation service providers and users bearing about 10.6 percent and 12.7 percent of the costs. This is still a significant increase, compared to the base case of 1.5 percent and 1.8 percent respectively (due to the operation costs from urea usage).

Even with these cost shifts, the overall production of locomotives and marine diesel engines and vessels is not expected to decrease significantly, and prices of rail and marine transportation services are not expected to increase significantly. There is no decrease in locomotive sales and commercial marine sales are expected to decrease by less than 200 units in 2011 and 2015 (less than 4 percent). Rail and marine transportation service prices are expected to increase by less than 1 percent. This is because rail and marine transportation services are production inputs for other goods and services, and an increase in their prices would be a relatively small increase to the total production costs of goods and services using these inputs.

Table 7H-4. Sensitivity Analysis for Supply Shifts: 2011[a]

	Variable Cost Only Supply Shift				Fixed and Variable Cost Supply Shift Scenario			
	Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives								
Locomotives	$425	-0.02%	0	-0.06%	$11,706	0.79%	0	-0.07%
Transportation services	NA	-0.12%	NA	-0.06%	NA	0.13%	NA	-0.07%
Marine								
Engines								
C1 >800 hp	$0	-0.00%	0	-0.00%	$24.557	16.82%	–9	–2.37%
C2 >800 hp	$0	-0.00%	0	-0.00%	$92,754	39.9%	–1	–1.28%
Other marine	$0	-0.00%	0	-0.00%	$739	4.99%	–45	–0.94%
Equipment								
C1 >800 hp	$0	-0.00%	0	-0.00%	$27.112	2.03%	–11	–2.37%
C2 >800 hp	$0	-0.00%	0	-0.00%	$264,897	7.21%	–1	–1.24%
Other marine	$0	-0.00%	0	-0.00%	$603	0.52%	–203	–0.64%
Transportation services	NA	-0.00%	NA	-0.00%	NA	0.10%	NA	–0.05%
Welfare Impacts (Million $)	**Surplus Change**		**Share**		**Surplus Change**		**Share**	
Locomotives								
Locomotive producers		–$11.1	5.5%			–$0.4	0.2%	
Rail transportation service providers		–$47.5	23.6%			–$52.3	26.1%	
Users of rail transportation service		–$57.0	28.3%			–$62.8	31.3%	
Total locomotive sector		–$115.6	57.3%			–$115.6	57.6%	
Marine								
Marine engine producers		–$86.0	42.7%			–$2.9	1.5%	
C1 >800 hp		–$22.8	11.3%			–$0.9	0.4%	
C2 >800 hp		–$27.8	13.8%			–$0.3	0.1%	
Other marine		$35.4	17.6%			–$1.8	0.9%	
Marine vessel producers		–$0.00	0.0%			–$24.9	12.4%	
C1 >800 hp		–$0.00	0.0%			–$8.7	4.3%	
C2 >800 hp		–$0.00	0.0%			–$1.9	0.9%	
Other marine		–$0.00	0.0%			–$14.4	7.2%	
Rec/fishing vessel consumers		–$0.00	0.0%			–$28.4	14.1%	
Marine transportation svc providers		–$0.00	0.0%			–$13.0	6.5%	
Users of marine transportation service		–$0.00	0.0%			–$15.6	7.8%	
Total marine sector		–$86.0	42.7%			–$84.9	42.4%	
Total program		–$201.5	100.0%			–$200.5	100.0%	

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[a] Figures are in 2005 dollars.

Table 7H-5. Sensitivity Analysis for Supply Shifts: 2015[a]

	Variable Cost Only Supply Shift				Fixed and Variable Cost Supply Shift Scenario			
	Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives								
Locomotives	$36,023	1.90%	0	-0.05%	$43,405	2.39%	0	-0.05%
Transportation services	NA	0.09%	NA	-0.05%	NA	0.10%	NA	-0.05%
Marine								
Engines								
C1 >800 hp	–$1	0.00%	0	0.00%	$27,274	18.71%	–16	–3.94%
C2 >800 hp	–$6	0.00%	0	–0.01%	$96,310	41.44%	–1	–1.55%
Other marine	$0	0.00%	0	0.00%	$0	0.00%	0	0.00%
Equipment								
C1 >800 hp	–$11	0.00%	0	0.00%	$45,071	3.37%	–20	–3.92%
C2 >800 hp	–$147	0.00%	0	–0.01%	$321,217	8.71%	–2	–1.51%
Other marine	$0	0.00%	0	0.00%	-$1	0.00%	0	0.00%
Transportation services	NA	0.02%	NA	–0.01%	NA	0.13%	NA	–0.07%
Welfare Impacts (Million $)	**Surplus Change**		**Share**		**Surplus Change**		**Share**	
Locomotives								
Locomotive producers		–$8.6	5.0%			–$0.4	0.2%	
Rail transportation service providers		–$38.2	22.2%			–$42.0	24.5%	
Users of rail transportation service		–$45.9	26.6%			–$50.4	29.5%	
Total locomotive sector		–$92.8	53.8%			–$92.7	54.5%	
Marine								
Marine engine producers		–$56.6	32.8%			–$1.8	1.1%	
C1 >800 hp		–$26.7	15.5%			–$1.5	0.9%	
C2 >800 hp		–$29.9	17.3%			–$0.3	0.2%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Marine vessel producers		–$17.5	10.2%			–$17.2	10.0%	
C1 >800 hp		–$12.5	7.2%			–$14.8	8.7%	
C2 >800 hp		–$5.0	2.9%			–$2.3	1.4%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Rec/fishing vessel consumers		$0.0	0.0%			–$19.5	11.4%	
Marine transportation svc providers		–$2.5	1.5%			–$18.1	10.6%	
Users of marine transportation service		–$3.1	1.8%			–$21.7	12.7%	
Total marine sector		–$79.8	46.2%			–$78.3	45.8%	
Total program		–$172.5	100.0%			–$171.0	100.0%	

[a] Figures are in 2005 dollars.

7H.3 Marine Operating Cost Scenario

In the primary case, all operating costs are allocated to the marine transportation service providers. This assumption likely overstates the share of the operating costs for this sector because it includes operating costs that are associated with recreational vessels that have marine diesel engines above 2,700 hp (2,000 kW) and with fishing vessels that have marine diesel engines above 800 hp (600 kW).

In this scenario, we attempt to allocate these extra operating costs to fishing and recreational vessels. The difficulty with this scenario is devising a way to allocate the costs. Because urea usage is a function of fuel use, it is reasonable to allocate the costs as a function of fuel usage. However, there is no publicly available data that indicates these fuel usage rates. Therefore, we estimate the fraction of operating costs as a function of the share of the total population. This method likely overstates the operating costs in the other direction, over-allocating the costs to recreational and fishing vessels. This is because this allocation method assumes that all vessels consume fuel in the same proportion; this is unlikely to be the case for recreational and fishing vessels, since usage of these vessels tends to be seasonal and they tend to be used for fewer hours a year. However, this sensitivity analysis will provide an indication of how sensitive the results are to differences in the allocation of operating costs.

The results of this analysis are contained in Table 7H-6. The market analysis shows a small increase in the price increase and a small decrease in the quantity decrease for marine diesel engines and vessels. There is also a small decrease in the amount of marine transportation services provided and a smaller increase in the price. The main change, not surprisingly, is smaller decreases in share of surplus loss for marine engine and vessel producers and a larger share of the surplus loss for recreational and fishing vessel consumers, from 3.3 percent ($7.8 million) to 5.4 percent ($12.9 million). There is a corresponding decrease in the share of surplus loss for marine transportation service providers and users, from 14.3 percent to 13.7 percent, and from 17.2 percent to 16.5 percent, respectively.

Table F-4. Sensitivity Analysis for Marine Operating Costs: 2020[a]

	Primary Case				Operating Cost Sensitivity			
	Change in Price		Change in Quantity		Change in Price		Change in Quantity	
Market–Level Impacts	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**	**Absolute**	**Percent**
Locomotives								
Locomotives	$48,092	2.54%	0	–0.08%	$48,092	2.54%	0	-0.08%
Transportation services	NA	0.16%	NA	–0.08%	NA	0.16%	NA	-0.08%
Marine								
Engines								
C1 >800 hp	$13,269	8.42%	–6	–1.35%	$13,189	8.37%	-6	-1.54%
C2 >800 hp	$48,818	18.74%	–1	–0.72%	$48,792	18.73%	-1	-0.75%
Other marine	$0	0.03%	0	0.00%	$0	0.00%	0	0.00%
Equipment								
C1 >800 hp	$16,331	1.14%	–7	–1.35%	$18,537	1.31%	-8	-1.54%
C2 >800 hp	$143,933	3.64%	–1	–0.71%	$152,840	3.87%	-1	-0.75%
Other marine	–$2	0.02%	–1	0.00%	-$2	0.00%	-1	0.00%
Transportation services	NA	0.24%	NA	–0.12%	NA	0.23%	NA	-0.12%
Welfare Impacts (Million $)	**Surplus Change**		**Share**				**Share**	
Locomotives								
Locomotive producers		-$0.7	0.3%			-$0.7	0.3%	
Rail transportation service providers		-$65.8	27.5%			-$65.8	27.5%	
Users of rail transportation service		-$78.9	32.9%			-$78.9	32.9%	
Total locomotive sector		-$145.3	60.7%			-$145.3	60.7%	
Marine								
Marine engine producers		-$0.8	0.3%			-$0.9	0.4%	
C1 >800 hp		-$0.6	0.2%			-$0.7	0.3%	
C2 >800 hp		-$0.2	0.1%			-$0.2	0.1%	
Other marine		$0.0	0.0%			$0.0	0.0%	
Marine vessel producers		-$10.1	4.2%			-$7.9	3.3%	
C1 >800 hp		-$7.8	3.3%			-$6.6	2.7%	
C2 >800 hp		-$2.3	0.9%			-$1.3	0.6%	
Other marine		-$0.1	0.0%			-$0.1	0.0%	
Rec/fishing vessel consumers		-$7.8	3.3%			-$12.9	5.4%	
Marine transportation service providers		-$34.3	14.3%			-$32.9	13.7%	
Users of marine transportation service		-$41.2	17.2%			-$39.5	16.5%	
Total marine sector		-$94.1	39.3%			-$94.1	39.3%	
Total program		-$239.5	100.0%			-$239.4	100.0%	

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[a] Figures are in 2005 dollars

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[22] Rutherford, T. 1998. “CES Preferences and Technology: A Practical Introduction.” *GAMS MPSGE Guide*. Washington, DC: GAMS Development Corporation.

CHAPTER 8: Regulatory Alternatives

Our proposal consists of a broad and comprehensive program to reduce emissions from locomotive and marine diesel engines. As we have developed this proposal, we have evaluated a number of alternatives with regard to the scope and timing of the proposed standards. We also examined an alternative that would require emission reductions from a significant fraction of the existing marine diesel engine fleet. This section presents a summary of our analysis of these alternative control scenarios. We believe our proposal to be superior to the alternatives considered here given the feasibility, cost, and environmental impact of each. In this chapter we present and discuss the alternative program options that we evaluated in order to make this determination.

8.1 Alternatives Considered

Our proposed emission control program consists of a two-step program to reduce NO_x and PM engine standards. The two steps consist of: (1) near-term emission standards that reflect the application of engine-based controls to new diesel marine engines and locomotives, and (2) long-term emission standards that reflect the application of high efficiency catalytic aftertreatment technology which will be enabled by the availability of clean diesel fuel with sulfur content capped at 15 parts per million. It also includes a locomotive remanufacturing program that sets new more stringent standards for Tier 0,1, and 2 applications. We have developed emission inventory impacts, cost estimates and benefit estimates for two types of alternatives. The first type looks at the impacts of varying the timing and scope of our proposed standards. The second considers a programmatic alternative that would set emission standards for existing marine diesel engines.

Table 8-1 Summary of Alternatives and Standards

Proposal	• Locomotive Remanufacturing • Tier 3 Near-term program • Tier 4 Long-term standards
Alternative 1: Exclusion of Locomotive Remanufacturing	• Tier 3 Near-term program • Tier 4 Long-term standards
Alternative 2: Tier 4 Advanced One Year	• Locomotive Remanufacturing • Tier 3 Near-term program • Tier 4 Long-term standards *moved ahead one year*
Alternative 3: Tier 4 Exclusively in 2013	• Tier 4 Long-term standards *moved ahead to 2013*
Alternative 4: Elimination of Tier 4	• Locomotive Remanufacturing • Tier 3 Near-term program
Alternative 5: Inclusion of Marine Remanufacturing	• Locomotive Remanufacturing • Tier 3 Near-term program • Tier 4 Long-term standards • Marine Remanufacturing

8.1.1 Alternative 1: Exclusion of Locomotive Remanufacturing

Alternative 1 examines the potential impacts of the locomotive remanufacturing program by excluding it from the analysis (see section III.C.(1)(a)(*i*) for more details of the locomotive remanufacturing program). It is identical to the proposal with the exception of the removal of the locomotive remanufacturing standards as the timing and scope of Tier 3 and Tier 4 standards remain unchanged in this alternative. These results can be compared with the results of the primary program to estimate the benefits that would be lost if we did not finalize the proposed locomotive remanufacturing program.

8.1.2 Alternative 2: Tier 4 Advanced One Year

Alternative 2 is the most stringent of our alternatives, and considers the possibility of pulling ahead the Tier 4 standards by one year for both the locomotive and marine programs, while leaving the rest of the proposed program the same. The timing and scope of both Tier 3 and the locomotive remanufacturing program would remain unchanged. These results can be compared with the results of the primary program to estimate the additional benefits that could occur if compliant engines were introduced one year earlier for both tiers of standards.

8.1.3 Alternative 3: Tier 4 Exclusively in 2013

Alternative 3 most closely reflects the program we described in our Advanced Notice of Proposed Rulemaking, whereby we would set new aftertreatment based emission standards as soon as possible. In this case, we believe the earliest that such standards could logical be started is in 2013 (3 months after the introduction of 15 ppm ULSD in this sector). This alternative would eliminate the Tier 3 standards and locomotive remanufacturing standards, while pulling the Tier 4 standards ahead to 2013 for all portions of the Tier 4 program. These results can be compared with the results of the primary program to estimate the benefits that would be lost if engine manufacturers were not required to develop emission control packages for near-term standards but, instead, could focus their efforts on the long-term standards.

8.1.4 Alternative 4: Elimination of Tier 4

Alternative 4 would eliminate the Tier 4 standards, retaining the Tier 3 and locomotive remanufacturing requirements. The timing and scope of both Tier 3 and the locomotive remanufacturing program would remain unchanged. These results can be compared with the results of the primary program to estimate the benefits that would be foregone if the more technology-forcing standards are not adopted at this time.

8.1.5 Alternative 5: Inclusion of Marine Remanufacturing

We are considering a fifth programmatic alternative which would impose a requirement on existing marine diesel engines similar to the existing remanufacture program for locomotives (see Section VI.A.2 of the preamble for further details). The standards would apply to engines above 800 hp and would consist of a two-part program. In the first part, which could begin as early as 2008, vessel owners and rebuilders (also called remanufacturers) would be required to use a certified kit when the engine is rebuilt (or remanufactured) if such a kit is available. Initially, these kits would be expected to be locomotive kits and therefore applicable only to those engines derived from similar locomotive engines. Eventually, however, it is expected that the large engine manufacturers would also provide kits for their engines. In the second part of this program, which could begin in 2013, the remanufacturer/owner of a marine diesel engine identified by the EPA as a high-sales volume engine model would have to meet specified emission requirements when the engine is remanufactured. Specifically, the remanufacturer or owner would be required to use a certified system to meet the standard; if no certified system is available, he or she would need to either retrofit an emission reduction technology for the engine that demonstrates at least a 25 percent reduction and does not exceed 0.22 g/kW-hr PM (equivalent to the new Tier 0/1 PM limit) or repower (replace the engine with a new one).

8.2 Emission Inventory Impacts

8.2.1 Methodology

8.2.1.1 Inventory Impacts

Based on our primary case, we estimated inventory impacts using a methodology based on engine population, hours of use, average engine loads, and in-use emissions factors for each alternative. (Refer to Chapter 3 of this Draft RIA for a more complete discussion of how the primary control inventories were generated). The results are shown in Table 8-1.

8.2.1.2 Costs

We have estimated the costs associated with each alternative using the same methods employed for the proposal. The cost estimates for the locomotive remanufacturing program include adjustments for costs associated with hardware requirements. The cost estimates for the marine remanufacturing program were generated in a similar manner as those generated for the proposed locomotive remanufacturing program. We have estimated the cost per remanufactured engine as equal to that for a remanufactured locomotive engine because we would expect a similar or identical remanufacture kit to be used. At this time, for alternatives 2 & 3 we are unable to make an accurate estimate of the cost for pulling ahead Tier 4 technologies, since we do not believe it to be feasible at this time. However, we have reported cost in the summary table reflecting the same cost estimation we have used for our primary case and have denoted unestimated additional costs as ‘C’. These additional unestimated costs would include costs for additional engine test cells, engineering staff, and engineering facilities necessary to accelerate the development of Tier 4. The details of our estimated remanufacturing program costs can be found in Chapter 5 of this draft RIA.

8.2.1.3 Benefits

To estimate the PM-related monetized benefits for each of the alternative scenarios, we used a benefits transfer approach to scale the PM benefits from the proposed Locomotive and Marine Engine control scenario. The PM benefits scaling approach is similar to the scaling approach conducted for the Clean Air Nonroad Diesel (CAND) Rule (see Chapter 9 of the CAND RIA). For the estimate of benefits generated for the proposal, we ran a sophisticated photochemical air quality model, the Community Multiscale Air Quality model (CMAQ), to estimate baseline and post-control ambient concentrations of PM for 2030. Benefits for the final proposed standards were then generated using the inputs and methods described in Chapter 6 of the draft RIA for this rule. We then scaled these PM benefits to reflect the magnitude of the PM2.5 precursor emissions changes estimated to occur as a result of the alternative control scenarios.

8.2.2 Analysis

Table 8-2 includes the expected yearly emission reductions associated with each alternative, including: the estimated PM and NO_x reductions for years 2006-2040 expressed as a net present value (NPV) using discounting rates of 3% and 7%. The yearly estimated costs are also expressed in this table at both 3% and 7% NPV. The benefit analysis from 2020 and 2030 is also included on this table. For further analysis, Table 8-3 and Table 8-4 summarize the PM and NO_x emission reductions and costs for each alternative; and Table 8-5 and Table 8-6 summarize the emission reductions, costs and benefits for the year 2020 and the year 2030. Figure 8.2-1 and Figure 8.2-2 illustrate the inventory impacts of each alternative from 2006-2040 for comparison.

Table 8-2 Inventory, Cost, and Benefits year from 2006-2040

	Primary Case				Alternative 1			
Calendar Year	PM$_{2.5}$ Emissions Reductions (tons)	NO$_X$ Emissions Reductions (tons)	Total Costs (Millions)	Benefits[a,b] (Billions) PM$_{2.5}$ only 2030 3% (7%)	PM$_{2.5}$ Emissions Reductions (tons)	NO$_X$ Emissions Reductions (tons)	Total Costs (Millions)	Benefits[a,b] (Billions) PM$_{2.5}$ only 2030 3% (7%)
2006	0	0	$0	---	0	0	$0	---
2007	0	0	$30	---	0	0	$30	---
2008	200	4,500	$50	---	0	0	$30	---
2009	600	4,700	$60	---	3	0	$30	---
2010	1,100	15,000	$90	---	6	0	$30	---
2011	2,200	33,000	$210	---	12	140	$100	---
2012	3,500	43,000	$140	---	350	1,800	$50	---
2013	4,500	56,000	$130	---	840	5,600	$50	---
2014	5,600	71,000	$120	---	1,600	18,000	$60	---
2015	6,800	84,000	$180	---	2,500	31,000	$130	---
2016	8,600	110,000	$200	---	3,700	51,000	$130	---
2017	10,000	160,000	$220	---	5,000	94,000	$160	---
2018	12,000	210,000	$230	---	6,400	140,000	$170	---
2019	13,000	250,000	$250	---	7,800	190,000	$190	---
2020	15,000	290,000	$250	$4.4-$9.2 ($4.0-$8.3)	9,300	230,000	$220	$3.2-$6.7 ($2.9-$6.0)
2021	16,000	340,000	$280	---	11,000	280,000	$250	---
2022	17,000	380,000	$330	---	12,000	330,000	$270	---
2023	19,000	440,000	$410	---	14,000	390,000	$370	---
2024	20,000	510,000	$430	---	15,000	460,000	$400	---
2025	21,000	550,000	$470	---	17,000	510,000	$430	---
2026	23,000	600,000	$480	---	19,000	560,000	$470	---
2027	24,000	640,000	$510	---	20,000	600,000	$500	---
2028	25,000	680,000	$550	---	22,000	650,000	$530	---
2029	27,000	720,000	$580	---	23,000	700,000	$560	---
2030	28,000	770,000	$610	$12-$25 ($11-$23)	25,000	740,000	$580	8.8-$19 ($8.0-$17)
2031	29,000	810,000	$630	---	26,000	780,000	$610	---
2032	30,000	850,000	$640	---	28,000	830,000	$640	---
2033	31,000	880,000	$730	---	29,000	870,000	$720	---
2034	32,000	920,000	$760	---	30,000	910,000	$750	---
2035	34,000	960,000	$790	---	32,000	950,000	$770	---
2036	35,000	1,000,000	$800	---	33,000	990,000	$790	---
2037	36,000	1,030,000	$820	---	34,000	1,000,000	$820	---
2038	37,000	1,060,000	$840	---	35,000	1,100,000	$840	---
2039	38,000	1,090,000	$860	---	37,000	1,100,000	$860	---
2040	38,000	1,120,000	$880	---	37,000	1,100,000	$870	---
2040 NPV 3%	315,000	7,870,000	$7,230	---	250,000	7,180,000	$6,430	---
2040 NPV 7%	135,000	3,180,000	$3,230	---	100,000	2,780,000	$2,700	---

[a] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[b] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

	Alternative 2				Alternative 3			
Calendar Year	$PM_{2.5}$ Emissions Reductions (tons)	NO_X Emissions Reductions (tons)	Total Costs (Millions)[a]	Benefits[b,c] (Billions) $PM_{2.5}$ only 2030 3% (7%)	$PM_{2.5}$ Emissions Reductions (tons)	NO_X Emissions Reductions (tons)	Total Costs (Millions)	Benefits[a,b] (Billions) $PM_{2.5}$ only 2030 3% (7%)
2006	0	0	$0	---	0	0	$0	---
2007	0	0	$30	---	0	0	$0	---
2008	200	4,500	$50	---	0	0	$50	---
2009	600	4,700	$80	---	0	0	$50	---
2010	1,100	15,000	$130	---	-8	0	$50	---
2011	2,200	33,000	$210	---	-16	0	$50	---
2012	3,500	43,000	$140	---	-27	0	$100	---
2013	4,700	62,000	$160	---	1,900	40,000	$130	---
2014	6,100	78,000	$180	---	2,700	81,000	$150	---
2015	7,300	100,000	$170	---	3,600	120,000	$150	---
2016	9,300	150,000	$220	---	4,900	160,000	$180	---
2017	11,000	200,000	$230	---	6,200	210,000	$200	---
2018	13,000	240,000	$250	---	7,500	250,000	$230	---
2019	14,000	290,000	$270	---	8,800	290,000	$260	---
2020	16,000	330,000	$270	$4.6-$9.7 ($4.2-$8.7)	10,000	340,000	$340	$3.6-$7.4 ($3.2-$6.7)
2021	17,000	370,000	$300	---	12,000	380,000	$370	---
2022	18,000	420,000	$360	---	13,000	430,000	$400	---
2023	19,000	500,000	$440	---	14,000	470,000	$430	---
2024	21,000	540,000	$460	---	16,000	520,000	$460	---
2025	22,000	580,000	$490	---	17,000	560,000	$490	---
2026	23,000	630,000	$500	---	19,000	600,000	$520	---
2027	25,000	670,000	$530	---	20,000	650,000	$550	---
2028	26,000	710,000	$570	---	22,000	690,000	$580	---
2029	27,000	750,000	$600	---	23,000	730,000	$600	---
2030	28,000	790,000	$620	$12-$25 ($11-$23)	25,000	770,000	$630	$11-$24 ($10-$21)
2031	30,000	830,000	$650	---	26,000	810,000	$650	---
2032	31,000	870,000	$660	---	27,000	850,000	$730	---
2033	32,000	910,000	$740	---	29,000	880,000	$760	---
2034	33,000	950,000	$770	---	30,000	920,000	$790	---
2035	34,000	980,000	$800	---	31,000	960,000	$810	---
2036	35,000	1,000,000	$810	---	32,000	990,000	$830	---
2037	36,000	1,000,000	$830	---	33,000	1,000,000	$850	---
2038	37,000	1,100,000	$850	---	34,000	1,100,000	$870	---
2039	38,000	1,100,000	$860	---	35,000	1,100,000	$890	---
2040	39,000	1,100,000	$880	---	36,000	1,100,000	$910	---
2040 NPV 3%	324,000	8,290,000	$7590 +C	---	255,000	8,050,000	$7410 +C	---
2040 NPV 7%	140,000	3,390,000	$3440 +C	---	104,000	3,280,000	$3220 +C	---

[a] The ‘C’ represents the additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time, such additional engine test cells, engineering staff, and engineering facilites necessary to introduce Tier 4 one year earlier.

[b] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[c] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality

	Alternative 4				Alternative 5			
Calendar Year	$PM_{2.5}$ Emissions Reductions (tons)	NO_X Emissions Reductions (tons)	Total Costs (Millions)	Benefits[a,b] (Billions) $PM_{2.5}$ only 2030 3% (7%)	$PM_{2.5}$ Emissions Reductions (tons)	NO_X Emissions Reductions (tons)	Total Costs (Millions)	Benefits[a,b] (Billions) $PM_{2.5}$ only 2030 3% (7%)
2006	0	0	$0	---	0	0	$0	---
2007	0	0	$28	---	0	0	$30	---
2008	200	4,500	$53	---	560	13,000	$80	---
2009	600	4,700	$60	---	1,300	20,000	$90	---
2010	1,100	15,000	$85	---	2,200	36,000	$120	---
2011	2,200	33,000	$160	---	3,700	58,000	$240	---
2012	3,500	43,000	$87	---	5,200	70,000	$180	---
2013	4,500	56,000	$79	---	6,700	87,000	$170	---
2014	5,600	71,000	$57	---	8,000	110,000	$160	---
2015	6,500	84,000	$47	---	9,000	120,000	$220	---
2016	7,800	110,000	$77	---	11,000	140,000	$220	---
2017	9,000	130,000	$61	---	13,000	190,000	$250	---
2018	9,900	140,000	$64	---	14,000	230,000	$270	---
2019	10,800	150,000	$58	---	16,000	270,000	$280	---
2020	11,000	160,000	$33	$3.2-$6.7 ($2.9-$6.0)	17,000	310,000	$280	$5.0-$10 ($4.5-$9.4)
2021	12,000	160,000	$33	---	18,000	350,000	$300	---
2022	13,000	170,000	$54	---	19,000	390,000	$350	---
2023	13,000	180,000	$45	---	20,000	450,000	$430	---
2024	14,000	190,000	$30	---	22,000	520,000	$460	---
2025	14,000	200,000	$32	---	23,000	560,000	$490	---
2026	15,000	210,000	$15	---	24,000	600,000	$490	---
2027	15,000	210,000	$14	---	25,000	650,000	$520	---
2028	16,000	220,000	$26	---	26,000	690,000	$570	---
2029	16,000	230,000	$25	---	28,000	730,000	$590	---
2030	17,000	240,000	$22	$6.2-$13 ($5.7-$12)	29,000	770,000	$620	$12-$26 ($11-$23)
2031	17,000	240,000	$19	---	30,000	810,000	$630	---
2032	18,000	250,000	$8	---	31,000	850,000	$640	---
2033	18,000	260,000	$7	---	32,000	890,000	$730	---
2034	19,000	270,000	$11	---	33,000	930,000	$760	---
2035	19,000	270,000	$14	---	34,000	960,000	$790	---
2036	19,000	280,000	$4	---	35,000	1,000,000	$800	---
2037	20,000	290,000	$4	---	36,000	1,000,000	$820	---
2038	20,000	290,000	$3	---	37,000	1,100,000	$840	---
2039	20,000	300,000	$3	---	38,000	1,100,000	$860	---
2040	21,000	300,000	$2	---	39,000	1,100,000	$880	---
2040 NPV 3%	207,000	2,910,000	$950	---	342,000	8,190,000	$7,650	---
2040 NPV 7%	94,000	1,310,000	$650	---	151,000	3,400,000	$3,510	---

[a] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[b] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

Table 8-3 Summary of Total Inventory and Costs Through 2040 NPV 3%

Program	$PM_{2.5}$ Emissions Reductions (tons) NPV 3%	NO_X Emissions Reductions (tons) NPV 3%	Total Costs (Millions) NPV 3%[a]
Primary Case	315,000	7,870,000	$7,230
Alternative 1: Exclusion of Locomotive Remanufacturing	250,000	7,180,000	$6,430
Alternative 2: Tier 4 Advanced One Year	324,000	8,290,000	$7,590+C
Alternative 3: Tier 4 Exclusively in 2013	255,000	8,050,000	$7,410+C
Alternative 4: Elimination of Tier 4	207,000	2,910,000	$950
Alternative 5: Inclusion of Marine Remanufacturing	342,000	8,190,000	$7,650

[a] 'C' represents additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time.

Table 8-4 Summary of Total Inventory and Costs Through 2040 NPV 7%

Program	$PM_{2.5}$ Emissions Reductions (tons) NPV 7%	NO_X Emissions Reductions (tons) NPV 7%	Total Costs (Millions) NPV 7%[a]
Primary Case	135,000	3,180,000	$3,230
Alternative 1: Exclusion of Locomotive Remanufacturing	100,000	2,780,000	$2,700
Alternative 2: Tier 4 Advanced One Year	140,000	3,390,000	$3,440+C
Alternative 3: Tier 4 Exclusively in 2013	104,000	3,280,000	$3,220+C
Alternative 4: Elimination of Tier 4	94,000	1,310,000	$650
Alternative 5: Inclusion of Marine Remanufacturing	151,000	3,400,000	$3,510

[a] 'C' represents additional costs necessary to accelerate the introduction of Tier 4 technologies that we are unable to estimate at this time.

Table 8-5 Summary of Inventory, Costs, and Benefits for 2020

	2020 $PM_{2.5}$ Emissions Reductions (tons)	2020 NO_X Emissions Reductions (tons)	2020 Total Costs (Millions)	2020 Benefits (Billions) $PM_{2.5}$ only 3% (7%)
Primary Case	15,000	290,000	$250	$4.4-$9.2 ($4.0$8.3)
Alternative 1	9,300	230,000	$220	$3.2-$6.7 ($2.9-$6.0)
Alternative 2	16,000	330,000	$270	$4.6-$9.7 ($4.2-$8.7)
Alternative 3	10,000	340,000	$340	$3.6-$7.4 ($3.2-$6.7)
Alternative 4	11,000	160,000	$33	$3.2-$6.7 ($2.9-$6.0)
Alternative 5	17,000	310,000	$280	$5.0-$10 ($4.5-$9.4)

[a] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[b] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

Table 8-6 Summary of Inventory, Costs, and Benefits for 2030

	2030 $PM_{2.5}$ Emissions Reductions (tons)	2030 NO_X Emissions Reductions (tons)	2030 Total Costs (Millions)	2030 Benefits[a,b] (Billions) $PM_{2.5}$ only 3% (7%)
Primary Case	28,000	770,000	$610	$12-$25 ($11-$23)
Alternative 1: Exclusion of Locomotive Remanufacturing	25,000	740,000	$580	$8.8-$19 ($8.0-$17)
Alternative 2: Tier 4 Advanced One Year	28,000	790,000	$620	$12-$25 ($11-$23)
Alternative 3: Tier 4 Exclusively in 2013	25,000	770,000	$630	$11-$24 ($10-$21)
Alternative 4: Elimination of Tier 4	17,000	240,000	$22	$6.2-$13 ($5.7-$12)
Alternative 5: Inclusion of Marine Remanufacturing	29,000	770,000	$620	$12-$26 ($11-$23)

[a] Note that the range of PM-related benefits reflects the use of an empirically-derived estimate of PM mortality benefits, based on the ACS cohort study (Pope et al., 2002) and the extension of the Harvard Six-Cities study (Laden et al. 2006).

[b] Annual benefits analysis results reflect the use of a 3 percent and 7 percent discount rate in the valuation of premature mortality and nonfatal myocardial infarctions, consistent with EPA and OMB guidelines for preparing economic analyses (US EPA, 2000 and OMB, 2003).U.S. Environmental Protection Agency, 2000. Guidelines for Preparing Economic Analyses. http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

Figure 8.2-1 $PM_{2.5}$ Inventories for 2006-2040

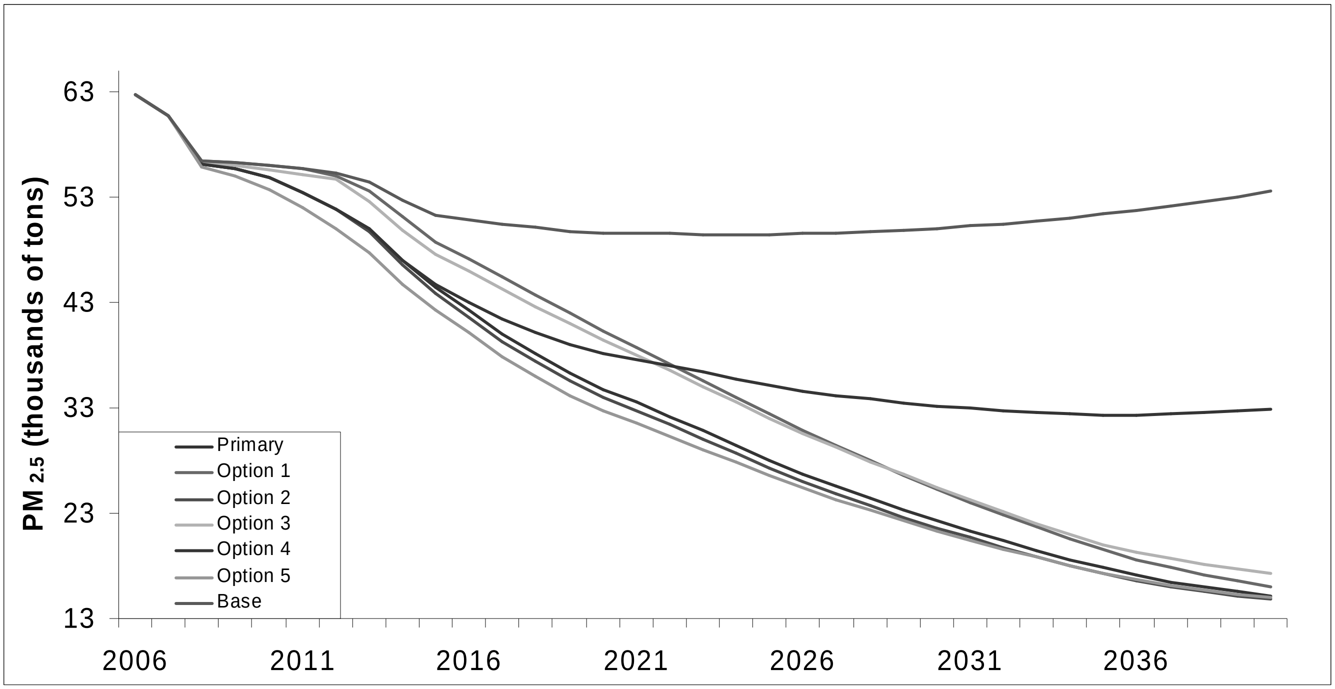
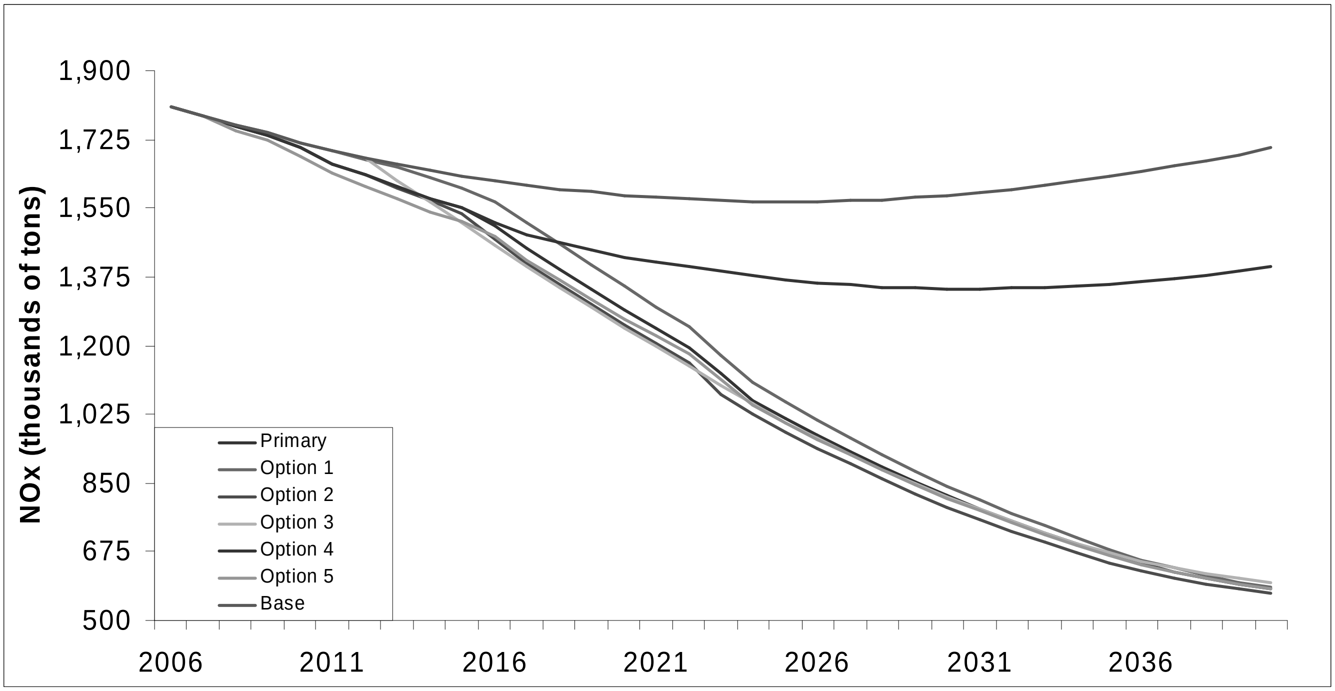


Figure 8.2-2 NO_x Inventories for 2006-2040



8.3 Summary of Results

8.3.1 Alternative 1: Exclusion of Locomotive Remanufacturing

Table 8-2 shows that the locomotive remanufacturing program provides substantial inventory impacts and benefits for a marginal increase in costs. This alternative shows that through 2040 the locomotive remanufacturing program would reduce $PM_{2.5}$ emissions by 65,000 tons NPV 3% (35,000 tons NPV 7%) and NO_x emissions by nearly 690,000 tons NPV 3% (400,000 tons at NPV 7%) at a cost of $870 million (NPV 3%). The monetized health and welfare benefits of the locomotive remanufacturing program in 2030 are $2.9-6.3 billion at a 3% discount rate (DR) or $2.7-$5.7 at a 7% DR. While this alternative could have the advantage of enabling industry to focus its resources on Tier 3 and Tier 4 technology development, given its substantial benefits, we have decided to retain the locomotive remanufacturing program in our proposal.

8.3.2 Alternative 2: Tier 4 Advanced One Year

This alternative is the most environmentally protective alternative we have given consideration to. However, our review of the technical challenges to introduce the Tier 4 program, especially in the context of the locomotive remanufacturing program and the Tier 3 standards which go before it, leads us to conclude that introducing Tier 4 a year earlier is not feasible. Our analysis suggests that introducing Tier 4 one year earlier than our proposal could reduce $PM_{2.5}$ emissions by 9,000 tons NPV 3% (5,000 tons NPV 7%) and NO_x emissions by 420,000 tons NPV 3% (210,000 tons NPV 7%). We are unable to make an accurate estimate of the cost for such an approach since we do not believe it to be feasible at this time. However, we have reported a cost in the summary table reflecting the same cost estimation method we have used for our primary case and have denoted unestimated additional costs as ‘C’. These additional unestimated costs would include costs for additional engine test cells, engineering staff, and engineering facilities necessary to introduce Tier 4 one year earlier.

8.3.3 Alternative 3: Tier 4 Exclusively in 2013

Alternative 3 most closely reflects the program we described in our Advanced Notice of Proposed Rulemaking, whereby we would set new aftertreatment based emission standards as soon as possible. In this case, we believe the earliest that such standards could logically be started in is 2013 (3 months after the introduction of 15 ppm ULSD in this sector). Alternative 3 eliminates our proposed Tier 3 standards and the locomotive remanufacturing standards, while pulling the Tier 4 standards ahead to 2013 for all portions of the Tier 4 program. As with alternative 2, we are concerned that it may not be feasible to introduce Tier 4 technologies on locomotive and marine diesel engines earlier than the proposal specifies. However, eliminating the technical work necessary to develop the Tier 3 and locomotive remanufacturing programs would certainly go a long way towards making such an approach possible. This alternative would actually result in substantially higher PM emissions than our primary case while reducing NO_x emissions. Through 2040 this alternative loses more than 60,000 tons NPV 3% (31,000 tons NPV 7%) of $PM_{2.5}$ reductions while only adding approximately 180,000 tons NPV 3% (100,000 tons NPV 7%) of NO_x reductions. As a result in 2030 alone, this alternative realizes approximately \$0.6-\$1.3 billion less at a 3% DR (\$0.5-\$1.2 billion less at a 7% DR) in public health and welfare benefits than does our proposal. As was the case with alternative 2, we have used the same cost estimation approach for this alternative as that of our proposal, and have denoted the unestimated costs that are necessary to accelerate the development of Tier 4 technologies with a ‘C’ in the summary tables. While alternative 3 could have been considered the Agency’s leading option going into this rulemaking process, our review of the technical challenges necessary to introduce Tier 4 technologies and the substantial additional benefits that a more comprehensive solution can provide has lead us to drop this approach in favor of the comprehensive proposal we have laid out today.

8.3.4 Alternative 4: Elimination of Tier 4

Alternative 4 would eliminate the Tier 4 standards and retain the Tier 3 and locomotive remanufacturing requirements. This alternative allows us to consider the value of combining the Tier 3 and locomotive remanufacturing standards together as one program, and conversely, allows us to see the additional benefits gained when combining them with the Tier 4 standards. As a stand alone alternative, the combined Tier 3 and locomotive remanufacturing program is very attractive, resulting in large emission reductions of 207,000 tons NPV 3% (94,000 tons NPV 7%) of $PM_{2.5}$ and 2,910,000 tons NPV 3% (1,310,000 tons NPV 7%) of NOx through 2040 at an estimated cost of \$950 million NPV 3% (\$650 million at NPV 7%) through the same time period. In 2030 alone, such a program is projected to realize health and welfare benefits of \$5.5-\$12 billion at a 3% DR (\$5.0-\$11 billion at a 7% DR). Yet, this alternative falls well short of the total benefits that our comprehensive program is expected to realize, and also would not take advantage of new aftertreatment technologies which have been developed and used on both nonroad and on-highway applications. Elimination of Tier 4 would result in the loss of 108,000 tons NPV 3% (41,000 tons NPV 7%) of $PM_{2.5}$ and almost 4,960,000 tons NPV 3% (1,870,000 tons NPV 7%) of NO_x through 2040. Through the addition of the Tier 4 standards, the estimated health and welfare benefits are nearly doubled in 2030. As these alternatives show, each element of our comprehensive program: the locomotive remanufacturing program, the Tier 3 emission standards, or the Tier 4 emission standards, represents a valuable emission control program on its own, while the collective program results in the greatest emission reductions we believe to be possible giving consideration to all of the elements described in today’s proposal.

8.3.5 Alternative 5: Inclusion of Marine Remanufacturing

This alternative would provide additional PM and NO_x benefits as shown in Figure 8.2-1 and Figure 8.2-2. With regard to benefits, the application of locomotive remanufacture kits to similar marine diesel engines would be expected to result in similar reductions in PM and NO_x emissions. In some cases, this could be as much as 60 percent reduction for PM and 25 percent reduction for NOx. However, because many marine diesel engines start at a cleaner baseline, we would not expect to accomplish the same reductions from all engines that would be subject to the program. Based on a minimal control case of a 25 percent PM reduction from existing marine diesel engines above 800 hp, we estimate about an additional 27,000 tons NPV 3% (16,000 tons NPV 7%) of $PM_{2.5}$ reductions, and an additional 320,000 tons NPV 3% (220,000 tons NPV 7%) of NO_x reductions through 2040. In general, we estimate that the compliance costs associated with this program to be about $10 million per year in additional costs in 2030. Using the benefits transfer approach from the primary control scenario to estimate the benefits of these inventory reductions, the additional monetized benefits would be expected to be about $0.3-$0.7 billion at a 3% DR ($0.3-$0.6 at a 7% DR) in 2030.