Chapter V: Economic Impact

A. Economic Impact of the 2007 Model Year Heavy-Duty Diesel Standards

This section contains an analysis of the economic impacts of the emission standards for heavy-duty diesel vehicles. First, a brief outline of the methodology used to estimate the economic impacts is presented, followed by a summary of the technology packages that are expected to be used to meet the standards. Next, the projected costs of the individual technologies are presented, along with a discussion of fixed costs such as research and development (R&D), tooling and certification. Following the discussion of the individual cost components is a summary of the projected per-vehicle cost of the regulations. Finally, an analysis of the aggregate cost for the new engine technologies is presented. Unless noted otherwise all costs presented here are in 1999 dollars.

1. Methodology for Estimating Costs

While the following analysis is based on a relatively uniform emission control strategy for designing the different categories of engines, this is not intended to suggest that a single combination of technologies will actually be used by all manufacturers. In fact, depending on basic engine emission characteristics, EPA expects that emission control technology packages will gradually be fine-tuned to each application. Furthermore, EPA expects manufacturers to use averaging, banking, and trading programs as a means to deploy varying degrees of emission control technologies on different engines. EPA nevertheless believes that the projections presented here provide a cost estimate representative of the different approaches manufacturers are likely to take.

Because many of the technologies which we believe will be used by the industry in order to meet the standards are being applied on a large scale for the first time, we have sought input from a large section of the regulated community, seeking their estimation of the future costs to apply these technologies. Under contract from EPA, ICF Consulting provided surveys to nine engine manufacturers seeking their input on expectations for cost savings which might be enabled through the use of low sulfur diesel fuel and seeking their estimations of the cost and types of emission control technologies which might be applied with low sulfur diesel fuel. Based on responses to these surveys, EPA estimated cost savings to the current and future fleets. The survey responses were also used as the first step in estimating the costs for advanced emission control technologies which may be applied in order to meet the 2007 heavy-duty vehicle standards.[1] These costs were then further refined by EPA based upon input from members of the Manufacturers of Emission Control Association.

Projected heavy-duty vehicle sale estimates are used in several portions of this analysis. Based on data submitted by engine manufacturers, we estimated 1995 engine sales to be 280,000 for light heavy-duty engines, 140,000 for medium heavy-duty engines, and 220,000 for heavy heavy-duty engines (including those sold into urban bus applications). These numbers are projected to grow at an annual rate of two percent of the base year without compounding through 2035 in this analysis and are included in table V.A-20.[2]

Costs of control include variable costs (for incremental hardware costs, assembly costs, and associated markups) and fixed costs (for tooling, R&D, and certification). For technologies sold by a supplier to the engine manufacturers, costs are either estimated based upon a direct cost to manufacture the system components plus a 29 percent markup to account for the supplier's overhead and profit, or when available, based upon estimates from suppliers on expected total costs to the manufacturers (inclusive of markups).[3] Estimated variable costs for new technologies include a markup to account for increased warranty costs. Variable costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer’s carrying cost was estimated to be four percent of the direct costs 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. This approach to individually estimating manufacturer and dealer markups, to better reflect the value added at each stage of the cycle, was adopted by EPA based upon industry input.[4]

EPA has also identified various factors that will cause cost impacts to decrease over time, making it appropriate to distinguish between near-term and long term costs. Research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts.[5] The analysis incorporates the effects of this learning curve as described in section A.6 of this chapter. Finally, manufacturers are expected to apply ongoing research to make emission controls more effective and to have lower operating costs over time.

Fixed costs for R&D are assumed to be incurred over the five-year period preceding introduction of the engine, tooling and certification costs are assumed to be incurred one year ahead of initial production. Fixed costs are increased by seven percent for every year before the start of production to reflect the time value of money, and are then recovered with a five-year amortization at the same rate. The analysis also includes consideration of lifetime operating costs where applicable. Projected costs were derived for the four service classes of heavy-duty diesel vehicles listed in Table V.A-1. The cost for each technology applied to urban buses is the same as the cost of that technology when applied to heavy heavy-duty vehicles, unless specified otherwise.

Table V.A-1. Service Classes of Heavy-Duty Vehicles

Service Class	*Vehicle Class*	*GVWR (lbs.)*
Light	2B - 5	8,500 - 19,500
Medium	6 - 7	19,501 - 33,000
Heavy	8	33,001 +
Urban Bus	—	—

2. Heavy-Duty Diesel Technologies for Compliance with the Standards

Several new technologies are projected for complying with the 2007 model year emission standards. We are projecting that NOx adsorbers and catalyzed diesel particulate filters will be the most likely technologies applied by the industry in order to meet our emissions standards. We also anticipate the introduction of closed crankcase filtration systems for turbocharged heavy-duty diesel engines due to the elimination of the current exception granted to these engines. The fact that manufacturers have several years before implementation of the new standards ensures that the technologies used to comply with the standards will develop significantly before reaching production. This ongoing development will lead to reduced costs in three ways. First, research will lead to enhanced effectiveness for individual technologies, allowing manufacturers to use simpler packages of emission control technologies than we would predict given the current state of development. Similarly, the continuing effort to improve the emission control technologies will include innovations that allow lower-cost production. Finally, 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 a combination of primary technology upgrades for the 2007 model year. Achieving very low NOx emissions will require basic research on NOx emission control technologies and improvements in engine management to take advantage of the aftertreatment system capabilities. The manufacturers are expected to take a systems approach to the problem optimizing the engine and aftertreatment system to realize the best overall performance possible. Since most research to date with aftertreatment technologies has focused on retrofit programs there remains room for significant improvements by taking such a systems approach. We have estimated that the catalyst companies will spend approximately $220 million to further develop the NOx and PM/HC control technologies described here. Further we have estimated that the engine manufacturers will spend approximately $385 million dollars on R&D to develop the control systems needed to take advantage of the advanced emission control technologies described here. The NOx adsorber technology in particular is expected to benefit from re-optimization of the engine management system to better match the NOx adsorber performance characteristics. The majority of the $385 million dollars we estimated for engine research is expected to be spent on developing this synergy between the engine and NOx aftertreatment systems. PM/HC control technologies are expected to be less sensitive to engine operating conditions as they have already shown good robustness in retrofit applications with low-sulfur diesel fuel. Nevertheless the manufacturers are expected to take a global systems approach that will optimize operation with consideration to both NOx and PM/HC emission control subsystems.

EPA contracted with ICF Consulting to 1) Estimate the variable cost for advanced emission control technologies which would be enabled by low sulfur diesel fuel, and 2) Estimate the impacts of low sulfur diesel fuel for engine durability and maintenance costs. Task 1 was completed by Engine, Fuel and Emissions Engineering and is referenced here as "Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content, Task 1," or as the EF&EE cost report. Task 2 was completed by ICF Consulting and is referenced here as "Economic Analysis of Vehicle and Engine Changes Made Possible by the Reduction of Diesel Fuel Sulfur Content, Task 2 - Benefits for Durability and Reduced Maintenance," or as the ICF low sulfur benefits report.

The results of our cost analysis are considered in the following paragraphs and summarized in Table V.A-2. Technology costs are described in section 3, fixed costs are described in section 4, and maintenance cost savings are described in section 5.

Table V.A-2. Summary of Near and Long Term Cost Estimates (net present value in year of sale)

Near Term (2007) Light Heavy-Duty Diesel Vehicles
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber System	\$87	\$925	\$0
Catalyzed Diesel Particulate Filter	\$41	\$690	\$55
HC and H_2S Clean Up Catalyst	\$0	\$206	\$0
Closed Crankcase System	\$0	\$37	\$31
Low Sulfur Diesel Fuel	\$0	\$0	\$576
Maintenance Savings	\$0	\$0	(\$153)
Total	\$128	\$1,858	\$509

Long Term (2012+) Light Heavy-Duty Diesel Vehicles
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	\$0	\$592	\$0
Catalyzed Diesel Particulate Filter	\$0	\$425	\$55
HC and H_2S Clean Up Catalyst	\$0	\$132	\$0
Closed Crankcase System	\$0	\$23	\$26
Low Sulfur Diesel Fuel	\$0	\$0	\$609
Maintenance Savings	\$0	\$0	(\$153)
Total	\$0	\$1,172	\$537

Near Term (2007) Medium Heavy-Duty Diesel Vehicles
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	$231	$1,080	$0
Catalyzed Diesel Particulate Filter	$98	$852	$56
HC and H_2S Clean Up Catalyst	$0	$261	$0
Closed Crankcase System	$0	$42	$59
Low Sulfur Diesel Fuel	$0	$0	$1,077
Maintenance Savings	$0	$0	($249)
Total	$329	$2,235	$943

Long Term (2012+) Medium Heavy-Duty Diesel Vehicles
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	$0	$691	$0
Catalyzed Diesel Particulate Filter	$0	$527	$56
HC and H_2S Clean Up Catalyst	$0	$167	$0
Closed Crankcase System	$0	$27	$48
Low Sulfur Diesel Fuel	$0	$0	$1,141
Maintenance Savings	$0	$0	($249)
Total	$0	$1,412	$996

Near Term (2007) Heavy Heavy-Duty Diesel Vehicles
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	$191	$1,456	$0
Catalyzed Diesel Particulate Filter	$89	$1,103	$208
HC and H_2S Clean Up Catalyst	$0	$338	$0
Closed Crankcase System	$0	$49	$218
Low Sulfur Diesel Fuel	$0	$0	$3,969
Maintenance Savings	$0	$0	($610)
Total	$280	$2,946	$3,785

Long Term (2012+) Heavy Heavy-Duty Diesel Vehicles
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	$0	$932	$0
Catalyzed Diesel Particulate Filter	$0	$686	$208
HC and H_2S Clean Up Catalyst	$0	$216	$0
Closed Crankcase System	$0	$32	$172
Low Sulfur Diesel Fuel	$0	$0	$4,209
Maintenance Savings	$0	$0	($610)
Total	$0	$1,866	$3,979

Near Term (2007) Urban Buses
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	$191	$1,456	$0
Catalyzed Diesel Particulate Filter	$89	$1,103	$98
HC and H_2S Clean Up Catalyst	$0	$338	$0
Closed Crankcase System	$0	$49	$107
Low Sulfur Diesel Fuel	$0	$0	$4,772
Current Oxidation Catalyst Removed	$0	($338)	$0
Maintenance Savings	$0	$0	($352)
Total	$280	$2,608	$4,625

Long Term (2012+) Urban Buses
(1999 Dollars per Engine)

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	$0	$932	$0
Catalyzed Diesel Particulate Filter	$0	$686	$98
HC and H_2S Clean Up Catalyst	$0	$216	$0
Closed Crankcase System	$0	$32	$92
Low Sulfur Diesel Fuel	$0	$0	$4,959
Current Oxidation Catalyst Removed	$0	($216)	$0
Maintenance Savings	$0	$0	($352)
Total	$0	$1,650	$4,797

3. Technology/Hardware Costs for Diesel Vehicles and Engines

The following discussion presents the projected costs of the primary technological improvements expected for complying with the emission standards detailing the variable costs of the individual technologies. EPA believes that a small set of technologies integrated into a single emission control system will represent the primary changes manufacturers must make to meet the 2007 model year standards. This integrated system is expected to include elements which could be individually identified as a NOx adsorber catalyst, a catalyzed diesel particulate filter, a diesel oxidation catalyst, and 15 ppm sulfur diesel fuel to enable the aforementioned emission control technologies. In order to comply with the requirement to eliminate crankcase emissions from all heavy-duty diesel engines, we are projecting the introduction of closed crankcase filtration systems. Lean NOx catalysts and compact SCR systems were not considered in this analysis, not because the control they offer is an incidental benefit, but because it appears unlikely that they will be part of 2007 model year technology packages.

a. NOx Adsorber Catalyst Costs

NOx adsorber catalysts have been developed and are being applied today for stationary power NOx emission control and for lean burn gasoline engine control. The application of this catalyst technology to diesel engines is relatively new. Therefore we have projected that there will be significant enhancements of the technology in order to better match the characteristics of diesel engines. Nevertheless the basic components of the NOx adsorber catalyst are well known and include, 1) an oxidation catalyst, typically platinum, 2) an alkaline earth metal to store NOx, typically barium, 3) a NOx reduction catalyst, typically rhodium, and 4) a substrate and can to hold and support the catalyst washcoat. Cost estimates for the NOx adsorber catalysts in 2007 are presented in Table V.A-3 below.

The material costs listed in Table V.A-3 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 NOx adsorber 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. This approach to individually estimating manufacturer and dealer markups, to better reflect the value added at each stage of the cycle, was adopted by EPA based upon industry input.[6]

We have estimated the cost of this system based on information from the following reports:

1. Estimated Economic Impact of New Emission Standards for Heavy-Duty On-Highway Engines, March 1997, EPA 420-R-97-009.
2. Cost Estimates for Heavy-Duty Gasoline Vehicles, September 1998, EPA Air Docket A-99-06 Item No. II-A-13.
3. Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content, December 1999, Air Docket A-99-06.

The individual assumptions used to estimate the cost for the system are documented in the following subsections.

Catalyst Volume

The Engine Manufacturers Association was asked as part of a contractor work assignment to gather input from their members on likely technology solutions including the NOx adsorber catalyst.[7] The respondents indicated that the catalyst volume for a NOx adsorber catalyst could range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on today's washcoating technology. Based on current lean burn gasoline catalyst designs and engineering judgement we have estimated that the NOx adsorber catalyst will be sized on average 1.5 times the engine displacement.

Substrate Cost

The ceramic flow through substrates used for the NOx adsorber catalyst are estimated to cost approximately $5 per liter. This cost estimate is based upon the relationship developed for current heavy-duty gasoline catalyst substrates as documented in Cost Estimates for Heavy-Duty Gasoline Vehicles of

$$C = \$4.67 \times V + \$1.50$$

where:

C = cost to the vehicle manufacturer from the substrate supplier
V = substrate volume in liters.

Washcoating and Canning

The report entitled, "Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content," estimates 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 the other components which are typically more widely available as commodities (e.g, precious metals and catalyst substrates). Here, we have taken the washcoating and canning costs estimated in the above mentioned report and have split out 11 percent of that cost for R&D, with the remaining 89 percent continuing to be called washcoat and canning. The R&D fraction is then used to estimate a total R&D expenditure for the industry due to the 2007 HD rule of $133 million recovered over the first five years of the program. We arrived at a value of 11 percent for R&D by looking at R&D costs as a fraction of gross profits from the annual report of one of the larger catalyst manufacturers.

Precious Metals

The total precious metal content for the NOx adsorber is estimated to be 50 g/ft^3 with platinum representing 90% of that total and Rhodium 10%. The costs for rhodium and platinum are the same as estimated in the Tier 2 RIA (EPA420-99-023) and are $868/troy oz. for rhodium and $412 / troy oz. for platinum.

Barium

The cost for barium carbonate (the primary NOx storage material) is assumed to be less than $1 per catalyst as estimated in “Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content.”

Can Housing

The material cost for the can housing is estimated based on the catalyst volume plus 20% for transition cones, plus 20% for scrappage (material purchased but unused in the final product) and a price of $.98/lb for 16 gauge stainless steel as estimated in contractor report “Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content.” The resulting material costs are summarized in the table below.

NOx Regeneration System

The NOx regeneration system is likely to include a NOx/O2 sensor, a means for exhaust air to fuel ratio control (one or more exhaust fuel injectors or in-cylinder means), a temperature sensor and possibly a means to control mass flow through a portion of the catalyst system (a “dual-bed” system). The cost for such a system is $300 for light and medium heavy-duty vehicles and $350 for heavy heavy-duty vehicles as estimated in contractor report “Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content.”

Direct Labor Costs

The direct labor costs for the catalyst are estimated based upon an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[8]

Warranty Costs

We have estimated the warranty costs based upon a 1% claim rate, and an estimate of parts and labor costs per incident. The labor rate is assumed to be $50 per hour, and a parts cost are estimated as 2.5 times the OEM component cost. These costs are summarized in the NOx absorber summary table below.

Manufacturer and Dealer Carrying Costs

The manufacturer's carrying cost was estimated at 4% of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3% of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.

Summary - Total System Estimate

Table V.A-3. 2007 NOx Adsorber Cost Estimate

NOx Adsorber Catalyst	*Vehicle Class*		
	LHDD	*MHDD*	*HHDD*
Catalyst Volume	9	12	20
Material Cost			
Substrate	$47	$63	$103
Washcoat (value added engineering)	$223	$267	$312
Platinum	$189	$253	$411
Rhodium	$44	$59	$96
Alkaline Earth Oxide	$1	$1	$1
Can Housing	$9	$13	$17
NOx Regeneration System	$300	$300	$350
Direct Labor Costs	$37	$37	$49
Total Direct Cost to Mfr.	$851	$992	$1,339
Warranty Costs (1% Claim Rate)	$22	$26	$34
Mfr. Carrying Cost	$26	$30	$40
Total Cost to Dealer	$899	$1,048	$1,413
Dealer Carrying Cost	$27	$31	$42
Total Cost to Customer	$925	$1,080	$1,456

b. Catalyzed Diesel Particulate Filter Costs

Catalyzed diesel particulate filters are already in limited production for retrofits in markets were low sulfur diesel fuel is available. The final design configurations and catalyst compositions that these technologies are likely to have in 2007 can be estimated with some accuracy. Based on current systems and input from industry, costs for catalyzed diesel particulate filters in 2007 were estimated and are presented in Table V.A-4 below. These cost are reduced here by $45 for light heavy-duty vehicles, $50 for medium heavy-duty vehicles and $55 for heavy heavy-duty vehicles to reflect the fact that diesel particulate filters also serve the function of a muffler, eliminating the need for that device.

Material costs for the catalyzed diesel particulate filter given here are inclusive of supplier markups as they reflect the expected cost to the engine manufacturer to purchase the hardware from a supplier. The total direct cost to the manufacturer includes an estimate of warranty costs for the catalyzed diesel particulate filter. 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 gives a three percent markup reflecting the cost of capital tied up in inventory. This approach to individually estimating manufacturer and dealer markups, to better reflect the value added at each stage of the cycle, was adopted by EPA based upon industry input.[9]

Diesel Particulate Filter Volume

The Engine Manufacturers Association was asked as part of a contractor work assignment to gather input from their members on catalyzed diesel particulate filters for heavy-duty applications.[10] The respondents indicated that the particulate filter volume could range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on today's experiences with cordierite filter technologies. The size of the diesel particulate filter is selected largely based upon the maximum allowable flow restriction for the engine. Generically the filter size is inversely proportional to its resistance to flow (a larger filter is less restrictive than an similar smaller filter). We have estimated that the diesel particulate filter will be sized to be 1.5 times the engine displacement in 2007 based on these responses and on-going research aimed at improving filter porosity control to give a better trade-off between flow restrictions and filtering efficiency.

Diesel Particulate Filter Costs

Cost estimates for cordierite diesel particulate filters (the most common type used today) were provided by several members of the Manufacturers of Emission Control Association (MECA) for each vehicle class. The cost estimates showed a non-linear relationship with particulate filter size with larger filters being somewhat less expensive per liter of filter volume. Here we have used an average of the MECA provided cost estimates for each of the classes to arrive at our cost estimate.[a]

[a] MECA member companies provided estimates of future cordierite filter costs to EPA's contractor EF&EE. EF&EE estimated the cost of future filters with a linear fit to the estimates provided. In this analysis, we have estimated the future cost of the cordierite filters by averaging the MECA member estimates for each vehicle class, rather than using the contractor's linear fit estimate. We used this alternate approach for estimating the cost of the cordierite filter due to the non-linear nature of the cost estimates provided by MECA. This change from the contractor's estimate increases the cost for light heavy-duty vehicles while decreasing the cost for heavy heavy-duty vehicles due to the non-linear nature of the cost estimates. The MECA estimates were identified as Confidential Business Information when provided to EF&EE and are therefore not provided in the docket associated with this RIA.

Washcoating and Canning

Washcoating and canning costs are estimated and accrued in the same manner as for the NOx adsorber technology discussed above. The resulting variable costs for washcoating and canning are $134 for light heavy-duty DPFs, $178 for medium heavy-duty DPFs, and $223 for heavy heavy-duty DPFs. Per filter R&D costs were estimated in the same manner as described above for the NOx adsorber catalyst and are estimated to be $16, $22, and $27 for diesel particulate filters applied to light, medium and heavy heavy-duty vehicles respectively. Aggregating these R&D costs over the projected engine volumes during the first five years of the program allows us to estimate the total R&D expense for catalyzed diesel particulate filters as $87 million.

Precious Metals

The total precious metal content for catalyzed diesel particulate filters is estimated to be 30 g/ft^3 with platinum as the only precious metal used in the filter. The cost for platinum is the same as estimated in the Tier 2 RIA (EPA420-99-023) and is $412/troy ounce.

Can Housing

The material cost for the can housing is estimated based on the filter volume plus 20% for transition cones, plus 20% for scrappage and a price of $.98/lb for 16 gauge stainless steel as estimated in contractor report "Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content." The resulting material costs are summarized in the table below.

Differential Pressure Sensor

We have assumed that the catalyzed diesel particulate filter system will require the use of a differential pressure sensor to provide a diagnostic monitoring function of the filter. A cost of $45 per sensor has been assumed as estimated in contractor report "Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content."

Direct Labor Costs

The direct labor costs for the catalyzed diesel particulate filter are estimated in contractor report "Economic Analysis of Diesel Aftertreatment System Changes Made Possible By Reduction of Diesel Fuel Sulfur Content" based upon an estimate of the number of hours required for assembly and established labor rates.

Warranty Costs

We have estimated the warranty costs based upon a 1% claim rate, and an estimate of parts and labor costs per incident. The labor rate is assumed to be $50 per hour, and a parts cost are estimated as 2.5 times the OEM component cost. These costs are summarized in the catalyzed diesel particulate filter summary table below.

Manufacturer and Dealer Carrying Costs

The manufacturer's carrying cost was estimated at 4% of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3% of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.

Muffler Costs

The diesel particulate filter costs are reduced here by $45 for light heavy-duty vehicles, $50 for medium heavy-duty vehicles and $55 for heavy heavy-duty vehicles to reflect the fact that diesel particulate filters also serve the function of a muffler, eliminating the need for that device.

Summary - Total System Estimate

Table V.A-4. 2007 Catalyzed Diesel Particulate Filter Cost Estimate

Catalyzed Diesel Particulate Filter	*Vehicle Class*		
	LHDD	*MHDD*	*HHDD*
Trap Volume (liters)	9	12	20
Material Cost			
Filter Trap	$300	$360	$420
Washcoat (value added engineering)	$134	$178	$223
Platinum	$126	$168	$274
Can Housing	$7	$10	$14
Differential Pressure Sensor	$45	$45	$45
Direct Labor Costs	$49	$49	$62
Total Direct Cost to Mfr.	$670	$822	$1,056
Warranty Costs (1% Claim Rate)	$16	$20	$25
Mfr. Carrying Cost	$27	$33	$42
Total Cost to Dealer	$713	$875	$1,124
Dealer Carrying Cost	$21	$26	$34
Savings by removing muffler	($45)	($50)	($55)
Total Cost to Customer	$690	$851	$1,103

c. Diesel Oxidation Catalyst (HC and H2S "Clean-Up" Catalyst)

The NOx adsorber regeneration and desulfation functions may produce undesirable by-products in the form of momentary increases in HC emissions or in odorous hydrogen sulfide (H2S) emissions. In order to control these potential products we have assumed that manufacturers may choose to apply a diesel oxidation catalyst (DOC) downstream of the NOx adsorber technology. The DOC would serve a "clean-up" function to oxidize any HC and H2S emissions to more desirable products as outlined in Chapter 3.

We have estimated the cost of diesel oxidation catalysts below in Table V.A-5 as $206 for a light heavy-duty diesel vehicle, $261 for a medium heavy-duty diesel vehicle and $338 for a heavy heavy-duty diesel vehicle. The individual component costs for the DOC were estimated in the same manner as for the NOx adsorber and CDPF above.

Table V.A-5. 2007 Diesel Oxidation Catalyst Cost Estimate

Catalyzed Diesel Particulate Filter	*Vehicle Class*		
	LHDD	*MHDD*	*HHDD*
Catalyst Volume (liters)	6	8	13
Material Cost			
Substrate	$32	$42	$69
Washcoat (value added engineering)	$125	$150	$175
Platinum (5 g/ft^3)	$14	$19	$30
Can Housing	$4	$6	$9
Direct Labor Costs	$13	$13	$13
Total Direct Cost to Mfr.	$187	$237	$308
Warranty Costs (1% Claim Rate)	$5	$6	$8
Mfr. Carrying Cost	$7	$9	$12
Total Cost to Dealer	$200	$253	$328
Dealer Carrying Cost	$6	$8	$10
Total Cost to Customer	$206	$261	$338

d. Closed Crankcase Filtration Systems

New engines introduced in Europe in the 2000 model year must have closed crankcases as part of the EURO III emission standards. The most common technology solution to this requirement is a closed crankcase filtration system which separates oil and other contaminants from the blow-by gases and then routes the blow-by gases into the engines intake system downstream of the air filter. An analysis of this type of control system was made as part of the 2004 heavy-duty rulemaking and system costs were estimated.[11] We have estimated the new vehicle cost of this type of closed crankcase system in Table V.A-6.

Table V.A-6. 2007 Closed Crankcase Filtration System Cost Estimate[12]

Closed Crankcase Filtration	*Vehicle Class*		
	LHDD	*MHDD*	*HHDD*
Hardware Costs			
Filter Housing	$10	$12	$15
Service Filter (30,000 mile interval)	$10	$12	$15
PCV Valve	$5	$5	$5
Tubing (plumbing)	$2	$2	$2
Assembly	$1	$1	$1
Total Variable Cost to Manufacturer	$28	$32	$38
Markup (@ 29%)	$8	$9	$11
Total CCV RPE	$37	$42	$49

Additionally there is a recurring cost for this type of system associated with the replacement of a service filter on a 30,000 mile interval. The cost for the service filter is estimated to be $10, $12, and $15 for light, medium, and heavy heavy-duty vehicles respectively. These operating costs are summarized in section 5 below along with other diesel vehicle operating costs.

4. Fixed Costs

Fixed costs are costs to the manufacturer which are non-recurring and include costs for research and development, tooling and new engine certification. The fixed costs for the diesel control portion of this rulemaking are given below. Expected expenditures are reported in the year incurred as non-annualized costs for PM/HC and NOx control separately. In general fixed costs are incurred prior to the introduction of the new vehicles and are assumed to be recovered over a five year period beginning with the first year of vehicle sale. Fixed costs are increased by seven percent for every year before the start of production to reflect the time value of money. The assumed recovery values for fixed costs associated with NOx and PM/HC control are given in the tables as annualized values.

a. Research and Development

The advanced emission control technologies which are likely to be applied in 2007 are already relatively well developed and are seeing application in retrofit markets where low sulfur diesel fuel is available or in other fields, such as power generation. Further development of these catalyst technologies to better adapt them to diesel applications is still needed however. We have estimated, based on current industry practices, that expenditures to further develop these advanced emission control technologies by the catalyst suppliers will be approximately $87 million for the CDPF technology and $133 million for the NOx adsorber technology (see description of these estimates section V.A.3.a and V.A.3.b above for each of these technologies).

Developing the integrated electronic engine control systems required to take advantage of these new emission reduction technologies for diesel engines will be a significant challenge for the diesel engine manufacturers. This is a large task which will entail complete re-optimization of diesel engine operation away from minimizing engine out emissions to minimizing total system emissions. In addition the manufacturers will need to develop a full understanding of the long term durability of the total emission control system in order to ensure compliance over the useful life of the vehicle and in order to develop deterioration factors (DFs) for the systems. We have therefore estimated that each of the 11 major diesel engine manufacturers will invest approximately $7 million per year on research and development over a period of five years to adapt their engine technology to the advanced emission control technologies described here. Seven million dollars represents the approximate cost for a team of more than 21 engineers and 28 technicians to carry out advanced engine research, including the cost for engine test cell time and prototype system fabrication. In total we have estimated that the engine manufacturers will spend approximately $385 million on R&D. Although we believe the manufacturers will take a total system approach optimizing the engine control system for PM/HC control and for NOx control concurrently, we have apportioned these research dollars separately for NOx and PM/HC due to the more complicated changes required to enable the NOx adsorber technology. We have apportioned 25 percent of the $385 million estimated for engine R&D to PM/HC control and the remaining 75 percent for development of the systems required for NOx control. These R&D costs are further apportioned between each vehicle classes based on the ratio of the number of engine families in a vehicle weight class to the total number of heavy duty diesel engine families.

The R&D costs for the advanced PM/HC emission control technologies are assumed to be incurred over the five year period from 2002 through 2006 and then recovered over the five year period starting in 2007. Research and development costs for the NOx adsorber system are assumed to be incurred in ratio to the NOx standard phase-in timetable and as such are spread over an eight year period beginning in 2002. For the vehicles introduced as part of the 50 percent NOx phase-in in 2007 these costs are assumed to be accrued in the five years preceding 2007 and to be fully recovered by 2011.

Tables V.A-7, V.A-8, and V.A-9 provide a year by year breakdown of the annualized and non-annualized costs for research and development for the light, medium and heavy heavy-duty vehicle categories. Fixed costs for urban buses are included in the cost estimates for heavy heavy-duty vehicles.

Table V.A-7. Annualized and Non-Annualized R&D Costs for Light Heavy-Duty Diesel Engines

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2002	0	0	$9,420,675	$0	$0	$10,300,813	$0	$0
2003	0	0	$9,420,675	$0	$0	$10,300,813	$0	$0
2004	0	0	$9,420,675	$0	$0	$10,300,813	$0	$0
2005	0	0	$9,420,675	$0	$0	$20,601,625	$0	$0
2006	0	0	$9,420,675	$0	$0	$20,601,625	$0	$0
2007	341,000	170,500	$0	$13,212,984	$39	$10,300,813	$14,447,422	$85
2008	346,600	173,300	$0	$13,212,984	$38	$10,300,813	$14,447,422	$83
2009	352,200	176,100	$0	$13,212,984	$38	$10,300,813	$14,447,422	$82
2010	357,800	357,800	$0	$13,212,984	$37	$0	$28,894,845	$81
2011	363,400	363,400	$0	$13,212,984	$36	$0	$28,894,845	$80
2012	369,000	369,000	$0	$0	$0	$0	$14,447,422	$78
2013	374,600	374,600	$0	$0	$0	$0	$14,447,422	$77
2014	380,200	380,200	$0	$0	$0	$0	$14,447,422	$76
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-8. Annualized and Non-Annualized R&D Costs for Medium Heavy-Duty Diesel Engines

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2002	0	0	$11,161,150	$0	$0	$13,811,325	$0	$0
2003	0	0	$11,161,150	$0	$0	$13,811,325	$0	$0
2004	0	0	$11,161,150	$0	$0	$13,811,325	$0	$0
2005	0	0	$11,161,150	$0	$0	$27,622,650	$0	$0
2006	0	0	$11,161,150	$0	$0	$27,622,650	$0	$0
2007	173,600	86,800	$0	$15,654,090	$90	$13,811,325	$19,371,098	$223
2008	176,400	88,200	$0	$15,654,090	$89	$13,811,325	$19,371,098	$220
2009	179,200	89,600	$0	$15,654,090	$87	$13,811,325	$19,371,098	$216
2010	182,000	182,000	$0	$15,654,090	$86	$0	$38,742,196	$213
2011	184,800	184,800	$0	$15,654,090	$85	$0	$38,742,196	$210
2012	187,600	187,600	$0	$0	$0	$0	$19,371,098	$207
2013	190,400	190,400	$0	$0	$0	$0	$19,371,098	$203
2014	193,200	193,200	$0	$0	$0	$0	$13,371,098	$201
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-9. Annualized and Non-Annualized R&D Costs for Heavy Heavy-Duty Diesel Engines and Urban Buses

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2002	0	0	$16,165,875	$0	$0	$18,102,013	$0	$0
2003	0	0	$16,165,875	$0	$0	$18,102,013	$0	$0
2004	0	0	$16,165,875	$0	$0	$18,102,013	$0	$0
2005	0	0	$16,165,875	$0	$0	$36,204,025	$0	$0
2006	0	0	$16,165,875	$0	$0	$36,024,025	$0	$0
2007	272,800	136,400	$0	$22,673,476	$83	$18,102,013	$25,389,009	$186
2008	277,200	138,600	$0	$22,673,476	$82	$18,102,013	$25,389,009	$183
2009	281,600	140,800	$0	$22,673,476	$81	$18,102,013	$25,389,009	$180
2010	286,000	286,000	$0	$22,673,476	$79	$0	$50,778,018	$178
2011	290,400	290,400	$0	$22,673,476	$78	$0	$50,778,018	$175
2012	294,800	294,800	$0	$0	$0	$0	$25,389,009	$172
2013	299,200	299,200	$0	$0	$0	$0	$25,389,009	$170
2014	303,600	303,600	$0	$0	$0	$0	$25,389,009	$167
2015	308,000	308,000	$0	$0	$0	$0	$0	$0

b. Tooling Costs

Capital costs for new, or changes to existing machine tooling, required to produce new engines to meet the standard are a fixed cost and are assumed to be incurred one year prior to the introduction of a new vehicle meeting the emission standard. The cost for the advanced aftertreatment systems, the NOx adsorber and catalyzed diesel particulate filter, discussed in section V.A.3 have been estimated based on cost to the engine manufacturer and are therefore inclusive of tooling cost to manufacture those items. Changes to the electronic control system and to the fuel and air management systems on the diesel engine may lead to some changes in tooling cost which are accounted for here. These systems are themselves expected to use the same hardware components developed to meet the 2004 heavy duty engine emission standards. Some changes may be necessary however, to accommodate the advanced aftertreatment systems described here. These changes are not expected to change the cost of the hardware itself in an appreciable way, but some tooling changes may be required. Since these tooling costs are intended to account for engine changes to the electronic control system and to the fuel and air management systems of the engine similar to those required for the Phase 1 standards, we have used the same tooling estimate for the Phase 2 engines here. These possible tooling costs have been estimated to be approximately $6 million for light heavy-duty engines, $9 million for medium heavy-duty engines, and $10 million for heavy heavy-duty engines and urban buses.[13]

The tooling costs have been apportioned evenly between NOx and PM/HC control technologies as these system changes are likely to be made based on optimizations for both types of aftertreatment system. The tooling charges apportioned for the NOx control technologies are assumed to occur in two equal steps sequenced with the phase-in period of the NOx standard. The tooling costs for each vehicle weight class are given in Tables V.A-10, V.A-11, and V.A-12.

Table V.A-10. Annualized and Non-Annualized Tooling Costs for Light Heavy-Duty Diesel Engines

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2005	0	0	$0	$0	$0	$0	$0	$0
2006	0	0	$2,775,000	$0	$0	$1,387,500	$0	$0
2007	341,000	170,500	$0	$724,172	$2	$0	$362,086	$2
2008	346,600	173,300	$0	$724,172	$2	$0	$362,086	$2
2009	352,200	176,100	$0	$724,172	$2	$1,387,500	$362,086	$2
2010	357,800	357,800	$0	$724,172	$2	$0	$724,172	$2
2011	363,400	363,400	$0	$724,172	$2	$0	$724,172	$2
2012	369,000	369,000	$0	$0	$0	$0	$362,086	$2
2013	374,600	374,600	$0	$0	$0	$0	$362,086	$2
2014	380,200	380,200	$0	$0	$0	$0	$362,086	$2
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-11. Annualized and Non-Annualized Tooling Costs for Medium Heavy-Duty Diesel Engines

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2005	0	0	$0	$0	$0	$0	$0	$0
2006	0	0	$4,443,000	$0	$0	$2,443,650	$0	$0
2007	173,600	86,800	$0	$1,159,459	$7	$0	$637,702	$7
2008	176,400	88,200	$0	$1,159,459	$7	$0	$637,702	$7
2009	179,200	89,600	$0	$1,159,459	$6	$2,443,650	$637,702	$7
2010	182,000	182,000	$0	$1,159,459	$6	$0	$1,275,405	$7
2011	184,800	184,800	$0	$1,159,459	$6	$0	$1,275,405	$7
2012	187,600	187,600	$0	$0	$0	$0	$637,702	$7
2013	190,400	190,400	$0	$0	$0	$0	$637,702	$7
2014	193,200	193,200	$0	$0	$0	$0	$637,702	$7
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-12. Annualized and Non-Annualized Tooling Costs for Heavy Heavy-Duty Diesel Engines and Urban Buses

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2005	0	0	$0	$0	$0	$0	$0	$0
2006	0	0	$5,132,750	$0	$0	$2,566,375	$0	$0
2007	272,800	136,400	$0	$1,339,458	$5	$0	$669,729	$5
2008	277,200	138,600	$0	$1,339,458	$5	$0	$669,729	$5
2009	281,600	140,800	$0	$1,339,458	$5	$2,566,375	$669,729	$5
2010	286,000	286,000	$0	$1,339,458	$5	$0	$1,339,458	$5
2011	290,400	290,400	$0	$1,339,458	$5	$0	$1,339,458	$5
2012	294,800	294,800	$0	$0	$0	$0	$669,729	$5
2013	299,200	299,200	$0	$0	$0	$0	$669,729	$4
2014	303,600	303,600	$0	$0	$0	$0	$669,729	$4
2015	308,000	308,000	$0	$0	$0	$0	$0	$0

c. Certification Costs

Manufacturers will also incur costs to certify the range of engine families to the emission standards. EPA previously developed a methodology for calculating certification costs which results in an estimated certification cost of $30,000 per engine family.[14] Here we have assumed that all engine families will require certification in 2007 with the introduction of the new PM and HC standards. Additionally as engine families are phased-in to meet the new NOx standards they will again require certification. We have assumed that in the first year of the NOx phase-in period 100 percent of the engine families will require certification and that in the fourth year of the phase (when 100 percent are phased in) that 50 percent of the engine families will require certification.

The total cost for certifying engines under this program can be rounded up to $5 million. Distributing those costs across the different engine categories, amortizing the costs over five years, and dividing by the number of projected sales for each category results in per-engine costs between $1 and $3 for each category of heavy-duty diesel vehicles. These costs are detailed in Tables V.A-13, V.A-14, and V.A-15 for each of the heavy-duty vehicle weight classes.

Table V.A-13. Annualized and Non-Annualized Certification Costs for Light Heavy-Duty Diesel Engines

Calendar	*Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2005	0	0	$0	$0	$0	$0	$0	$0
2006	0	0	$480,000	$0	$0	$0	$0	$0
2007	341,000	170,500	$0	$125,262	$0.4	$0	$0	$0
2008	346,600	173,300	$0	$125,262	$0.4	$0	$0	$0
2009	352,200	176,100	$0	$125,262	$0.4	$240,000	$0	$0
2010	357,800	357,800	$0	$125,262	$0.4	$0	$62,631	$0.3
2011	363,400	363,400	$0	$125,262	$0.3	$0	$62,631	$0.3
2012	369,000	369,000	$0	$0	$0	$0	$62,631	$0.3
2013	374,600	374,600	$0	$0	$0	$0	$62,631	$0.3
2014	380,200	380,200	$0	$0	$0	$0	$62,631	$0.3
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-14. Annualized and Non-Annualized Certification Costs for Medium Heavy-Duty Diesel Engines

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2005	0	0	$0	$0	$0	$0	$0	$0
2006	0	0	$1,020,000	$0	$0	$0	$0	$0
2007	173,600	86,800	$0	$266,182	$1.5	$0	$0	$0
2008	176,400	88,200	$0	$266,182	$1.5	$0	$0	$0
2009	179,200	89,600	$0	$266,182	$1.5	$510,000	$0	$0
2010	182,000	182,000	$0	$266,182	$1.5	$0	$133,091	$1.5
2011	184,800	184,800	$0	$266,182	$1.4	$0	$133,091	$1.4
2012	187,600	187,600	$0	$0	$0	$0	$133,091	$1.4
2013	190,400	190,400	$0	$0	$0	$0	$133,091	$1.4
2014	193,200	193,200	$0	$0	$0	$0	$133,091	$1.4
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-15. Annualized and Non-Annualized Certification Costs for Heavy Heavy-Duty Diesel Engines and Urban Buses

Calendar	*Projected Vehicle Sales*		*PM/HC Control*			*NOx Control*		
Year	*meeting PM/HC Std*	*meeting NOx Std*	*non-annualized*	*annualized*	*ann. per vehicle*	*non-annualized*	*annualized*	*ann. per vehicle*
2005	0	0	$0	$0	$0	$0	$0	$0
2006	0	0	$1,200,000	$0	$0	$0	$0	$0
2007	272,800	136,400	$0	$313,156	$1.2	$0	$0	$0
2008	277,200	138,600	$0	$313,156	$1.1	$0	$0	$0
2009	281,600	140,800	$0	$313,156	$1.1	$600,000	$0	$0
2010	286,000	286,000	$0	$313,156	$1.1	$0	$156,578	$1.1
2011	290,400	290,400	$0	$313,156	$1.1	$0	$156,578	$1.1
2012	294,800	294,800	$0	$0	$0	$0	$156,578	$1.1
2013	299,200	299,200	$0	$0	$0	$0	$156,578	$1.1
2014	303,600	303,600	$0	$0	$0	$0	$156,578	$1.0
2015	308,000	308,000	$0	$0	$0	$0	$0	$0

d. Summary of Fixed Costs

The total annualized fixed costs are summarized here for light, medium and heavy heavy-duty vehicles. Fixed costs for urban buses are included in the estimates for heavy heavy-duty diesel vehicles. Research and Development costs account for over 90 percent of the total fixed costs per engine in our analysis. Tables V.A-16, V.A-17 and V.A-18 below summarize fixed costs in each year of the program.

Table V.A-16. Annualized Fixed Costs for Light Heavy-Duty Diesel Engines

Calendar	*Projected Vehicle Sales*		*PM/HC Control*		*NOx Control*		*Total*	
Year	*meeting PM/HC Std*	*meeting NOx Std*	*annualized*	*annualized per vehicle*	*annualized*	*annualized per vehicle*	*annualized*	*annualized per vehicle*
2007	341,000	170,500	$14,062,419	$41	$14,809,509	$87	$28,871,92	$128
2008	346,600	173,300	$14,062,419	$41	$14,809,509	$85	$28,871,92	$126
2009	352,200	176,100	$14,062,419	$40	$14,809,509	$84	$28,871,92	$124
2010	357,800	357,800	$14,062,419	$39	$29,681,648	$83	$43,744,06	$122
2011	363,400	363,400	$14,062,419	$39	$29,681,648	$82	$43,744,06	$121
2012	369,000	369,000	$0	$0	$14,872,140	$81	$14,872,14	$81
2013	374,600	374,600	$0	$0	$14,872,140	$79	$14,872,14	$79
2014	380,200	380,200	$0	$0	$14,872,140	$78	$14,872,14	$78
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-17. Annualized Fixed Costs for Medium Heavy-Duty Diesel Engines

Calendar	Projected Vehicle Sales		PM/HC Control		NOx Control		Total	
Year	meeting PM/HC Std	meeting NOx Std	annualized	annualized per vehicle	annualized	annualized per vehicle	annualized	annualized per vehicle
2007	173,600	86,800	$17,079,731	$98	$20,008,800	$231	$37,088,531	$329
2008	176,400	88,200	$17,079,731	$97	$20,008,800	$227	$37,088,531	$324
2009	179,200	89,600	$17,079,731	$95	$20,008,800	$223	$37,088,531	$318
2010	182,000	182,000	$17,079,731	$94	$40,150,691	$221	$57,230,422	$315
2011	184,800	184,800	$17,079,731	$92	$40,150,691	$217	$57,230,422	$309
2012	187,600	187,600	$0	$0	$20,141,891	$215	$20,141,891	$215
2013	190,400	190,400	$0	$0	$20,141,891	$212	$20,141,891	$212
2014	193,200	193,200	$0	$0	$20,141,891	$209	$20,141,891	$209
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-18. Annualized Fixed Costs for Heavy Heavy-Duty Diesel Engines and Urban Buses

Calendar	Projected Vehicle Sales		PM/HC Control		NOx Control		Total	
Year	meeting PM/HC Std	meeting NOx Std	annualized	annualized per vehicle	annualized	annualized per vehicle	annualized	annualized per vehicle
2007	272,800	136,400	$24,326,090	$89	$26,058,738	$191	$50,384,828	$280
2008	277,200	138,600	$24,326,090	$88	$26,058,738	$188	$50,384,828	$276
2009	281,600	140,800	$24,326,090	$86	$26,058,738	$185	$50,384,828	$271
2010	286,000	286,000	$24,326,090	$85	$52,274,054	$183	$76,600,144	$268
2011	290,400	290,400	$24,326,090	$84	$52,274,054	$180	$76,600,144	$264
2012	294,800	294,800	$0	$0	$26,215,316	$178	$26,215,316	$178
2013	299,200	299,200	$0	$0	$26,215,316	$175	$26,215,316	$175
2014	303,600	303,600	$0	$0	$26,215,316	$173	$26,215,316	$173
2015	308,000	308,000	$0	$0	$0	$0	$0	$0

5. Operating Costs

Operating costs include the cost for vehicle and engine maintenance, and the cost for vehicle consumables such as fuel, oil, filters and tires. The new standards and technologies introduced beginning in 2007 are expected to change vehicle operating costs. Costs for the refining and distribution of diesel fuel are expected to change due to the 15 ppm sulfur requirement. These costs are examined in detail later in this chapter (section V.D), but are also summarized here on a per vehicle basis. The closed crankcase systems we have described here include a paper filter element which is changed on a fixed service interval. The cost of this filter is included here as an ongoing operating cost. In addition the reduction of the sulfur content in diesel fuel is expected to lead to reduced maintenance costs or other cost savings in the design of future diesel engines. These cost savings are discussed in detail for both new and existing engines in section V.C and are summarized here on a per vehicle basis. The advanced emission control technologies expected to be applied in order to meet the NOx and PM/HC standards involve wholly new system components integrated into engine designs and calibrations, and as such may be expected to change the fuel consumption characteristics of the overall engine design. A discussion of the potential impacts of these technologies on vehicle fuel economy, and an explanation of why we do not expect vehicle fuel economy levels to change from today's levels are given here. All of these operating cost impacts are described here and are used to present a total per vehicle cost for control in tables V.A-2 and V.A-19.

a. Low Sulfur Diesel Fuel

Low sulfur diesel fuel is a primary enabling technology without which the other previously mentioned emission control technologies could not be applied. As an essential part of the technology package which enables the standards its cost are summarized here and in table V.A-2 on a per-vehicle cost basis (NPV).

The low-sulfur diesel fuel required to enable these technologies is expected to have a long term incremental cost of approximately $0.05/gallon as discussed in more detail later in this chapter. This per gallon cost can be accounted for on a per vehicle basis by considering the mileage typically driven by a class of vehicle at each year of its life and the average fuel economy. Using that approach and bringing the total cost back to a net present value in the year of sale gives a long term per vehicle low sulfur fuel cost of $609 for a light heavy-duty vehicle, $1,141 for a medium heavy-duty vehicle, $4,209 for a heavy heavy-duty vehicle and $4,959 for an urban bus. For a more detailed discussion of the cost associated with low sulfur diesel fuel please refer to section V.D in this RIA.

b. Maintenance Costs for Closed Crankcase Ventilation Systems (CCV)

We have eliminated the exception that allows turbo-charged heavy-duty diesel engines to vent crankcase gases directly to the environment without accounting for these emissions, sometimes called open crankcase systems, and are projecting that manufacturers will rely on engineered closed crankcase ventilation systems which filter oil from the blow-by gases in order to satisfy the emission standard. An integral part of the system described in Chapter III of this RIA is a paper filter designed to capture oil mist in the blow-by gases, coalesce this oil and return this filtered oil to the oil sump. These filters are expected to require replacement on a fixed interval of 30,000 miles.

The cost of these filters in 2007 has been estimated to be $10, $12, and $15 for light, medium, and heavy heavy-duty vehicles respectively. The variable cost for these replacement filters are reduced in future years due to the learning curve effect as described in section 6 below. The long term total life cycle operating cost for the filter replacements expressed as a net present value in the year of sale is $26, $48, and $172 for light, medium, and heavy heavy-duty vehicles, respectively. Urban bus life cycle operating costs are estimated to be $92. To account for the aggregate cost of filter replacement the filter costs are estimated on a per mile basis for each class of vehicle (for example for heavy heavy-duty this is $15/30,000 miles) and then are estimated in total using typical mileage accumulation rates given in each year of a vehicles life from our inventory emissions model. The results of this calculation along with the maintenance costs for CDPFs are reported in table V.A-21.

c. Maintenance Costs for Catalyzed Diesel Particulate Filters

The particulate matter (PM) emitted from diesel engines consists primarily of elemental carbon formed during the combustion process from diesel fuel. This elemental carbon is captured in the CDPF and then oxidized to CO_2 and emitted from the engine. A very small fraction of the PM consists of inorganic metals which are also captured by the CDPF but are not emitted later from the CDPF. Instead this inorganic "ash" accumulates in the PM filter over time slowing filling the filtering passages of the CDPF. Current engine oil formulations are the primary source of this inorganic ash due to metal additives used in the oil.

The inorganic ash captured in the CDPF can be cleaned from the CDPF by removing it from the vehicle and reverse flushing the ash out of the CDPF with compressed air or water. Current industry guidelines suggest a maintenance interval for retrofit applications of approximately 60,000 miles for CDPF cleaning. This guideline reflects a fairly short maintenance interval because

- PM rates in retrofit applications are high (many retrofits are EURO 0, I, & II engines)[15]
- Oil consumption rates on older retrofit engines can be very high
- Current engine oils are highly additized to maintain Total Base Number (TBN).

We have estimated that for CDPF equipped vehicles in 2007 and beyond that the maintenance interval will increase to 100,000 miles for light heavy-duty vehicles and 150,000 miles for medium and heavy heavy-duty vehicles. We expect that this interval will be planned to coincide with other engine maintenance events and can be extended to these higher intervals because

- PM rates are lower for modern diesel engines
- Modern diesel engines have low oil consumption rates (to meet the PM standard)
- Low sulfur diesel fuel will allow the use of "low ash" engine oils.

We have estimated the cost of this service based upon the assumption that the service is scheduled to coincide with other service intervals and that the dominant cost for the service is the cost labor cost to remove and clean the filter. We have assumed that this removal and reinstallation will take approximately one hour. We have used a labor rate for this service event of $65 / hour. These costs are aggregated on a fleet wide basis in each year of the program and reported in table V.A-21 along with the maintenance costs for the closed crankcase ventilation (CCV) system. The CDPF maintenance costs can also be expressed as a net present value in the year of sale for an individual vehicle as $55 for a light heavy-duty vehicle, $56 for a medium heavy-duty vehicle, $208 for a heavy heavy-duty vehicle and $107 for an urban bus.

d. Maintenance Savings due to Low Sulfur Diesel Fuel

In addition to its role as a technology enabler, low sulfur diesel fuel gives benefits in the form of reduced sulfur induced corrosion and slower acidification of engine lubricating oil, leading to longer maintenance intervals and lower maintenance costs. These benefits are described in detail in section V.C and result in an estimated savings of $153 for light heavy-duty vehicles, $249 for medium heavy-duty vehicles, and $610 for heavy heavy-duty vehicles and urban buses.

e. Fuel Economy Impacts

Diesel particulate filters are anticipated to provide a step-wise decrease in diesel particulate (PM) emissions by trapping PM and by oxidizing the diesel PM and hydrocarbon (HC) emissions. The trapping of the very fine diesel PM is accomplished by forcing the exhaust through a porous filtering media with extremely small opening and long path lengths.[b] This approach 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 additional pumping work is anticipated to negatively impact fuel economy by approximately one percent.[16] However as detailed in the following discussion this fuel economy penalty is more than offset through optimization of the engine-PM trap-NOx adsorber system, as discussed below.

NOx adsorbers are expected to be the primary NOx control technology introduced in order to provide the reduction in NOx emissions necessary to meet the NOx standard. NOx adsorbers work by storing NOx emissions under fuel lean operating conditions (normal diesel engine operating conditions) and then by releasing and reducing the stored NOx emissions over a brief period of fuel rich engine operation. This brief periodic NOx release and reduction step is directly analogous to the catalytic reduction of NOx over a gasoline three-way-catalyst. In order for this catalyst function to occur the engine exhaust constituents and conditions must be similar to normal gasoline exhaust constituents. That is, the exhaust must be fuel rich (devoid of excess oxygen) and hot (over 250°C). Although it is anticipated that diesel engines can be made to operate in this way, it is assumed that the fuel economy of the diesel engine operating under these conditions will be worse than normal. This increase in fuel consumption can be minimized by carefully controlling engine air-to-fuel (A/F) ratios using the EGR systems introduced in order to meet the 2004 heavy duty engine emission standards. The lower the engine A/F ratio, the lower the amount of fuel which must be added in order to give rich conditions. In the ideal case where the engine A/F ratio is at stoichiometry, and additional fuel is required only as a NOx reductant the fuel economy penalty is virtually zero. We are projecting, that practical limitations on engine A/F control will mean that the NOx adsorber release and reduction cycles will lead to a one

[b] Typically the filtering media is a porous ceramic monolith or a metallic fiber mesh.

percent decrease in the engine fuel economy. Again, we believe this fuel economy impact can be regained through optimization of the engine-PM trap-NOx adsorber system.

In addition to the NOx release and regeneration event, another step in NOx adsorber operation may affect fuel economy. NOx adsorbers are poisoned by sulfur in the fuel even at the low sulfur levels we have set today. Chapter III of this RIA describes how the sulfur poisoning of the NOx adsorber can be reversed through a periodic "desulfation" event. The desulfation of the NOx adsorber is accomplished in a manner similar to the NOx release and regeneration cycle described above. However it is anticipated that the desulfation event will require extended operation of the diesel engine at rich conditions.[17] This rich operation will, like the NOx regeneration event, will lead to an increase in the fuel consumption rate and will cause an associated decrease in fuel economy. With a 15 ppm fuel sulfur cap, we are projecting this fuel economy penalty to be one percent or less as described in more detail in chapter III of this RIA. Again, we believe this fuel economy impact can be regained through optimization of the engine-PM trap-NOx adsorber system.

While NOx adsorbers require non-power producing consumption of diesel fuel in order to function properly and, therefore, have an impact on fuel economy, they are not unique among NOx control technologies in this way. In fact NOx adsorbers are likely to have a very favorable NOx to fuel economy trade-off when compared to other popular NOx control technologies like cooled EGR and injection timing retard. EGR requires the delivery of exhaust gas from the exhaust manifold to the intake manifold of the engine and causes a decrease in fuel economy for two reasons. The first of these reasons is that a certain amount of work is required to pump the EGR from the exhaust manifold to the intake manifold; this necessitates the use of intake throttling or some other means to accomplish this pumping. The second of these reasons is that heat in the exhaust, which is normally partially recovered as work across the turbine of the turbocharger, is instead lost to the engine coolant through the cooled EGR heat exchanger. In the end, cooled EGR is only some 50 percent effective at reducing NOx below the current 4 g/bhp-hr NOx emission standard. Injection timing retard is another strategy that can be employed to control NOx emissions. By retarding the introduction of fuel into the engine, and thus delaying the start of combustion, both the peak temperature and pressure of the combustion event are decreased; this lowers NOx formation rates and, ultimately, NOx emissions. Unfortunately, this also significantly decreases the thermal efficiency of the engine (lowers fuel economy) while also increasing PM emissions. As an example, retarding injection timing eight degrees can decrease NOx emissions by 45 percent, but this occurs at a fuel economy penalty of more than seven percent.[18]

Today, most diesel engines rely on injection timing control (retarding injection timing) in order to meet the 4.0 g/bhp-hr NOx emission standard. For 2002/2004 model year compliance, we expect that engine manufacturers will use a combination of cooled EGR and injection timing control to meet the 2.0 g/bhp-hr NOx standard. Because of the more favorable fuel economy trade-off for NOx control with EGR when compared to timing control, we have forecast that less reliance on timing control will be needed in 2002/2004. Therefore, fuel economy will not be changed even at this lower NOx level. NOx adsorbers have a significantly more favorable NOx to fuel economy trade-off when compared to cooled EGR or timing retard.[19] We expect NOx adsorbers to be able to accomplish a greater than 90 percent reduction in NOx emissions, while themselves consuming significantly less fuel than that lost through alternative NOx control strategies such as retarded injection timing.[c] Therefore, we expect manufacturers to take full advantage of the NOx control capabilities of the NOx adsorber and project that they will decrease reliance on the more expensive (from a fuel economy standpoint) technologies, especially injection timing retard. We would, therefore, predict that the fuel economy impact currently associated with NOx control from timing retard will be decreased by at least three percent. In other words, through the application of these advanced NOx emission control technologies, we expect the NOx trade-off with fuel economy to continue to improve significantly when compared to today's technologies. This will result in much lower NOx emissions and potentially overall improvements in fuel economy, improvements that could easily offset the one percent fuel economy loss projected to result from the application of PM filters. For our analysis of economic impacts, no penalty or benefit for changes to fuel economy is assumed.

In order to illustrate the sensitivity of cost to fuel economy, we have calculated the benefit (or cost) of a one percent change in vehicle fuel economy as a sensitivity analysis to these possible changes. For a light heavy-duty engine a one percent change in vehicle fuel economy expressed as a net present value in the year of sale is approximately $100, for a medium heavy-duty engine it is approximately $200, for a heavy heavy-duty engine it is approximately $800. The amount of the benefit (or cost) of a one percent change in fuel economy expressed in terms of its annual impact on the entire fleet of engines meeting the 2007 NOx standards can be estimated as $155 million in 2010 and $459 million in 2030. These potential benefits (or costs) represent approximately 4 percent of the total program cost in 2010 and less than 11 percent in 2030.

6. Summary of Near and Long Term Costs

We have estimated in section V.A.3 the cost of a technology package which is representative of the technologies we expect industry to apply to meet our standards. These cost estimates represent an expected incremental cost of engines in the 2007 model year. EPA has also identified various factors that would cause cost impacts to decrease over time, making it

[c] EPA has estimated the fuel consumption rate for NOx regeneration and desulfation of the NOx adsorber as approximately 2 percent of total engine fuel consumption. This differs from the contractor report by EF&EE which estimates the total consumption as approximately 2.5% of total fuel consumption. Additionally the contractor's estimate of NOx adsorber efficiency ranges from 80-90 percent, while EPA believes over 90 percent control is possible as discussed fully in Chapter III of this RIA.

appropriate to distinguish between near-term and long term costs. These factors are described below and the resulting near and long term per vehicle costs are presented here.

First, initial fixed costs for tooling, R&D, and certification are recovered over a five-year period phased with the NOx standard phase-in period. Fixed costs are therefore accrued in four periods corresponding to each of the phase-in years of the NOx standard. The accrued costs are then recovered over a five year period.

For variable costs, research in the costs of manufacturing has shown that as manufacturers gain experience in production, they are able to lower the per-unit cost of production. These effects are often described as the manufacturing learning curve.[20]

The learning curve is a well documented phenomenon dating back to the 1930s. The general concept is that unit costs decrease as cumulative production increases. Learning curves are often characterized in terms of a progress ratio, where each doubling of cumulative production leads to a reduction in unit cost to a percentage "p" of its former value (referred to as a "p cycle"). The organizational learning which brings about a reduction in total cost is caused by improvements in several areas. Areas involving direct labor and material are usually the source of the greatest savings. Examples include, but are not limited to, a reduction in the number or complexity of component parts, improved component production, improved assembly speed and processes, reduced error rates, and improved manufacturing process. These all result in higher overall production, less scrappage of materials and products, and better overall quality. As each successive p cycle takes longer to complete, production proficiency generally reaches a relatively stable plateau, beyond which increased production does not necessarily lead to markedly decreased costs.

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[21] The distribution of these progress ratios is shown in Figure V-1. Except for one company that saw *increasing* costs as production continued, every study showed cost savings of at least five percent for every doubling of production volume. The average progress ratio for the whole data set falls between 81 and 82 percent. Other studies (Alchian 1963, Argote and Epple 1990, Benkard 1999) appear to support the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

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

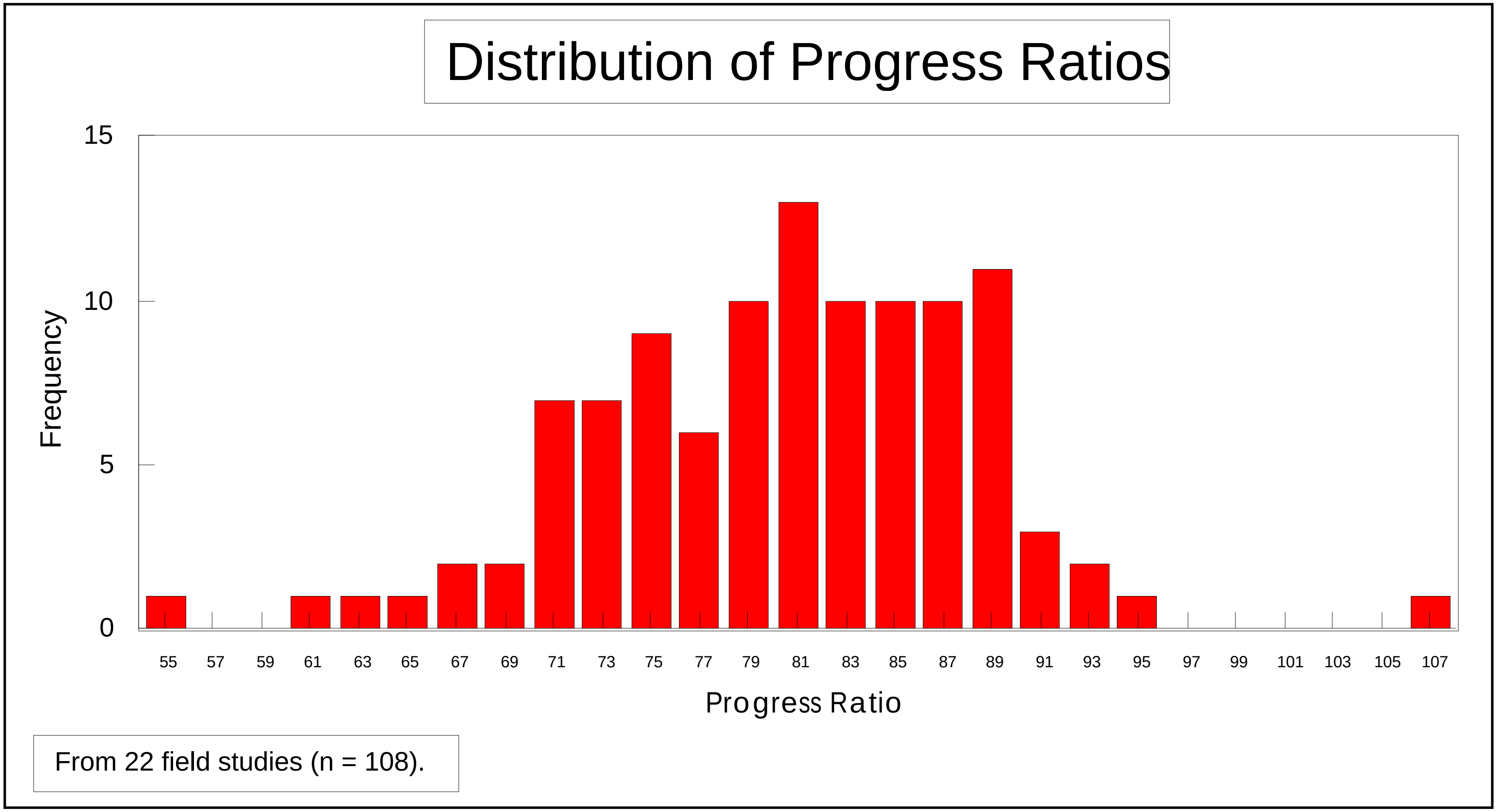

Figure V.A-1. Distribution of Progress Ratios
(Dutton and Thomas, 1984)

doubling of cumulative output is associated with 11% decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

EPA believes the use of the learning curve is appropriate to consider in assessing the cost impact of heavy-duty engine emission controls. The learning curve applies to new technology, new manufacturing operations, new parts, and new assembly operations. Heavy-duty diesel engines currently do not use any form of NOx aftertreatment and have used diesel particulate filters in only limited application. These are therefore new technologies for heavy-duty diesel engines and will involve new manufacturing operations, new parts, and new assembly operations. Since this will be a new and unique product, EPA believes this is an appropriate situation for the learning curve concept to apply. Opportunities to reduce unit labor and material costs and increase productivity (as discussed above) will be great. EPA believes a similar opportunity exists for the new control systems which will integrate the function of the engine and the emission control technologies. While all diesel engines beginning in 2004 are expected to have the basic components of this system, advanced engine control modules (computers), advanced engine air management systems (cooled EGR, and variable geometry turbocharging) and advanced fuel systems including common rail systems, they will now be applied in new ways. Additionally some new components will be applied for the first time. These new parts and new assemblies will involve new manufacturing operations. As manufacturers gain experience with these new systems, comparable learning is expected to occur with respect to unit labor and material costs. These changes require manufacturers to start new production procedures, which, over time, will improve with experience.

We have applied a p value of 80 percent beginning in 2007 in this analysis. That is, variable costs were reduced by 20 percent for each doubling of cumulative production. With one year as the base unit of production, the first learning curve is applied at the start of 2009. The second doubling of production occurs at the end of the 2010 model year, therefore variable costs are reduced a second time by 20 percent beginning in the 2011 model year. In Tier 2, and in the heavy-duty gasoline cost analysis presented in section B of this chapter, the learning curve reduction was applied only once because we anticipated that for the most part the standards will be met through improvements to existing technologies rather than through the use of new technologies. With existing technologies, there will be less opportunity for lowering production costs.

Fixed costs for this program have been allocated for two separate groups of vehicle representing vehicles introduced in the first and fourth years of NOx phase in period. In this way fixed costs on a per vehicle basis are appropriately weighted for the number of vehicles introduced in that model year. The manufacturers are expected to accrue fixed cost in proportion to the number of vehicles being introduced in a model year as we have done here. This means that fixed costs are assumed to begin accruing in 2002 for vehicles intended for introduction in

2007 and to continue to be accrued through 2009 for vehicles intended for introduction in 2010. Fixed costs are therefore assumed to be recovered beginning in 2007 (for vehicles introduced in 2007) and continuing through 2014 for vehicles introduced in 2010, the final year of the NOx phase-in. For all per vehicle costs, the fixed costs are reported for vehicles first introduced in 2007 and are therefore fully recovered by 2012. For a more complete description of fixed costs see section V.A.4 of this RIA.

The resulting hardware and life cycle operating costs for new vehicles developed to meet the new 2007 heavy-duty vehicle standards are summarized in table V.A-19 below.

Table V.A-19. Projected Incremental Diesel Engine/Vehicle Costs (net present value at point of sale in 1999 dollars)

Vehicle Class	*Model Year*	*Change*	*Hardware Cost*	*Life-cycle Operating Cost (NPV)*
Light heavy-duty	2007	—	$1,986	$509
	2009	20 percent learning curve applied to variable costs	$1,601	$509
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,173	$537
Medium heavy-duty	2007	—	$2,564	$943
	2009	20 percent learning curve applied to variable costs	$2,096	$943
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,412	$996
Heavy heavy-duty	2007	—	$3,227	$3,785
	2009	20 percent learning curve applied to variable costs	$2,618	$3,785
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,866	$3,979
Urban Bus	2007	—	$2,889	$4,625
	2009	20 percent learning curve applied to variable costs	$2,347	$4,625
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,650	$4,797

It is appropriate to compare the impact of these incremental costs to the total cost to purchase and operate these vehicles. The analysis for the 2004 heavy duty engine standards included work to document the cost to purchase and operate heavy duty vehicles. That analysis is carried forward here and is given in Table V.A-20 after being adjusted to 1999 dollars. From the table we can see that in the near term and long term vehicle operating costs can be expected to increase by less four percent for all vehicle weight classes. Near term vehicle costs on average will be expected to increase by approximately five percent. In the long term vehicle costs will be increased by less than five percent for light heavy-duty vehicles, by less than three percent for medium heavy-duty vehicles, and by less than two percent heavy heavy-duty vehicles and urban buses.

Table V.A-20. Baseline Costs for Heavy-Duty Engines and Vehicles [22]

Vehicle Class	*Engine Cost*	*Vehicle Cost*	*Operating Costs*
Light heavy-duty	$8,527	$24,600	$13,610
Medium heavy-duty	$13,555	$50,430	$34,153
Heavy heavy-duty	$23,722	$105,481	$118,093
Urban Bus	$24,050	$244,871	$477,885

7. Total Incremental Nationwide Costs for 2007 Heavy-Duty Diesel Engines

The above analysis develops per-vehicle cost estimates for each vehicle class. With current data for the size and characteristics of the heavy-duty vehicle fleet and projections for the future, these costs can be translated into a total cost to the nation for the emission standards in any year. The result of this analysis are presented in the following tables which summarize the total incremental cost for new vehicles introduced into the fleet for each model year.

Fixed costs have been previously developed for each class of heavy duty vehicle and are presented in section V.A.4 of this RIA. Those costs have been totaled here to present the total annualized and non-annualized fixed costs for the engine control under this program. Variable costs are computed as a product of one full year of heavy-duty vehicle sales and the cost increase for the new hardware on a per vehicle basis as developed previously. The operating cost for the closed crankcase filtration systems and for cleaning CDPF catalysts are included here as well. The operating cost associated with low sulfur diesel fuel and the savings associated with low sulfur diesel fuel are summarized on an aggregate basis later in this chapter.

The total annualized cost for the hardware changes are given in table V.A-21 below. Non-annualized costs are also given below in table V.A-22.

Table V.A-21. Estimated Annualized Nationwide Costs for Heavy-Duty Diesel Engines Associated with the 2007 Emission Standard
(1999 dollars)

Calendar Year	*Projected Vehicle Sales*	*Fixed Costs*	*Variable Costs*	*CCV and CDPF Maintenance Costs*	*Total Costs*
2007	787,400	$116,345,286	$1,373,511,459	$22,066,902	$1,511,923,648
2008	800,200	$116,345,286	$1,395,802,627	$58,732,341	$1,570,880,255
2009	813,000	$116,345,286	$1,126,415,636	$82,987,152	$1,325,748,074
2010	825,800	$177,574,633	$1,521,698,170	$110,217,085	$1,809,489,888
2011	838,600	$177,574,633	$1,227,885,771	$123,307,106	$1,528,767,511
2012	851,400	$61,229,347	$1,246,599,207	$143,989,773	$1,451,818,326
2013	864,200	$61,229,347	$1,265,312,642	$162,942,107	$1,489,484,096
2014	877,000	$61,229,347	$1,284,026,077	$180,369,083	$1,525,624,507
2015	889,800	$0	$1,302,739,513	$196,453,205	$1,499,192,718
2016	902,600	$0	$1,321,452,948	$211,356,424	$1,532,809,372
2017	915,400	$0	$1,340,166,383	$225,221,746	$1,565,388,129
2018	928,200	$0	$1,358,879,819	$238,175,421	$1,597,055,240
2019	941,000	$0	$1,377,593,254	$250,327,361	$1,627,920,615
2020	953,800	$0	$1,396,306,689	$261,771,775	$1,658,078,464
2021	966,600	$0	$1,415,020,124	$272,586,752	$1,687,606,876
2022	979,400	$0	$1,433,733,560	$282,835,130	$1,716,568,690
2023	992,200	$0	$1,452,446,995	$292,570,241	$1,745,017,236
2024	1,005,000	$0	$1,471,160,430	$301,857,197	$1,773,017,627
2025	1,017,800	$0	$1,489,873,866	$310,779,520	$1,800,653,386
2026	1,030,600	$0	$1,508,587,301	$319,383,848	$1,827,971,149
2027	1,043,400	$0	$1,527,300,736	$327,711,027	$1,855,011,763
2028	1,056,200	$0	$1,546,014,172	$335,796,605	$1,881,810,777
2029	1,069,000	$0	$1,564,727,607	$343,671,733	$1,908,399,340
2030	1,081,800	$0	$1,583,441,042	$351,363,512	$1,934,804,554
2031	1,094,600	$0	$1,602,154,478	$358,926,832	$1,961,081,310
2032	1,107,400	$0	$1,620,867,913	$366,345,968	$1,987,213,881
2033	1,120,200	$0	$1,639,581,348	$373,585,640	$2,013,166,988
2034	1,133,000	$0	$1,658,294,784	$380,771,649	$2,039,066,433
2035	1,145,800	$0	$1,677,008,219	$387,852,302	$2,064,860,521

Table V.A-22. Estimated Non-Annualized Nationwide Costs for Heavy-Duty Diesel Engines Associated with the 2007 Emission Standard (1999 dollars)

Calendar Year	*Fixed Costs*	*Variable Costs*	*CCV and CDPF Maintenance Costs*	*Total Costs*
2002	$78,961,850	$0	$0	$78,961,850
2003	$78,961,850	$0	$0	$78,961,850
2004	$78,961,850	$0	$0	$78,961,850
2005	$121,176,000	$0	$0	$121,176,000
2006	$142,624,275	$0	$0	$142,624,275
2007	$42,214,150	$1,373,511,459	$22,066,902	$1,437,792,511
2008	$42,214,150	$1,395,802,627	$58,732,341	$1,496,749,118
2009	$49,961,675	$1,126,415,636	$82,987,152	$1,259,364,463
2010	$0	$1,521,698,170	$110,217,085	$1,631,915,255
2011	$0	$1,227,885,771	$123,307,106	$1,351,192,877
2012	$0	$1,246,599,207	$143,989,773	$1,390,588,980
2013	$0	$1,265,312,642	$162,942,107	$1,428,254,749
2014	$0	$1,284,026,077	$180,369,083	$1,464,395,160
2015	$0	$1,302,739,513	$196,453,205	$1,499,192,718
2016	$0	$1,321,452,948	$211,356,424	$1,532,809,372
2017	$0	$1,340,166,383	$225,221,746	$1,565,388,129
2018	$0	$1,358,879,819	$238,175,421	$1,597,055,240
2019	$0	$1,377,593,254	$250,327,361	$1,627,920,615
2020	$0	$1,396,306,689	$261,771,775	$1,658,078,464
2021	$0	$1,415,020,124	$272,586,752	$1,687,606,876
2022	$0	$1,433,733,560	$282,835,130	$1,716,568,690
2023	$0	$1,452,446,995	$292,570,241	$1,745,017,236
2024	$0	$1,471,160,430	$301,857,197	$1,773,017,627
2025	$0	$1,489,873,866	$310,779,520	$1,800,653,386
2026	$0	$1,508,587,301	$319,383,848	$1,827,971,149
2027	$0	$1,527,300,736	$327,711,027	$1,855,011,763
2028	$0	$1,546,014,172	$335,796,605	$1,881,810,777
2029	$0	$1,564,727,607	$343,671,733	$1,908,399,340
2030	$0	$1,583,441,042	$351,363,512	$1,934,804,554
2031	$0	$1,602,154,478	$358,926,832	$1,961,081,310
2032	$0	$1,620,867,913	$366,345,968	$1,987,213,881
2033	$0	$1,639,581,348	$373,585,640	$2,013,166,988
2034	$0	$1,658,294,784	$380,771,649	$2,039,066,433
2035	$0	$1,677,008,219	$387,852,302	$2,064,860,521

B. Economic Impact of the 2008 Model Year Heavy-Duty Gasoline Standards

This chapter contains an analysis of the economic impacts of the emission standards for 2008 model year heavy-duty gasoline vehicles and engines. First, a brief outline of the methodology used to estimate the economic impacts is presented, followed by a summary of the technology packages that are expected to be used to meet the standards. Next, the projected costs of the individual technologies is presented, along with a discussion of fixed costs such as research and development (R&D), tooling and certification costs. Following the discussion of the individual cost components is a summary of the projected per-vehicle cost. Finally, an analysis of the aggregate cost to society of the new standards is presented. The costs presented here are in 1999 dollars.

1. Methodology for Estimating Heavy-Duty Gasoline Costs

This analysis uses the emission control technology packages assumed for the final Phase 1 gasoline standards as a baseline from which changes will be made to comply with the new Phase 2 standards. The Phase 1 standards go into effect for the 2004 or 2005 model year.[23] That is, we have identified the changes we expect to be made to the assumed 2005 baseline vehicles in complying with the new 2008 standards. The 2005 baseline technology packages are consistent with those being implemented to meet California's Low Emission Vehicle (LEV I) standards. The technology packages assumed for the 2008 model year are consistent with those expected to meet the California LEV-II medium-duty vehicle standards and our light-duty Tier 2 standards.[d,24] The catalyst system costs of these technologies are taken from the Phase 1 RIA, which are based on a report done for EPA by Arcadis Geraghty & Miller.[25] Other system costs are taken from the final Tier 2 RIA, which are based in part on California's LEV-II analysis and the same Arcadis Geraghty & Miller report.

The costs of meeting the 2008 emission standards include both variable costs (incremental hardware costs, assembly costs, and associated markups) and fixed costs (tooling, R&D, and certification costs). Supplier markups, those markups occurring between the part or emission control system supplier to the vehicle or engine manufacturer, are applied to catalyst costs in this analysis because the cost we estimated for each element comprising the catalyst are the supplier cost rather than the vehicle or engine manufacturer cost. This contrasts with the diesel cost analysis discussed in Section V.A where the cost of each element comprising a PM trap or a NOx adsorber are costs to the vehicle manufacturer (i.e., they already contain a supplier

[d] While the Tier 2 standards are light-duty standards, and do not apply to the vehicles and engines covered by this analysis, we expect that the technologies employed to meet the Tier 2 standards will transfer in large part into the heavy-duty gasoline fleet; therefore, the types of technology packages are expected to be very similar.

markup). An exception to applying the supplier markup has been made for precious metals. Vehicle manufacturers typically provide catalyst suppliers with precious metals for use in the catalysts their suppliers manufacture. Thus, the 29 percent supplier markup is not applied to the cost of precious metals. The supplier markup is already reflected in the non-catalyst system costs (e.g., EGR system, secondary air injection system, etc.) presented in this section.

The variable costs to the manufacturer have then been marked up twice.[26] The first markup, at a four percent rate, covers manufacturer carrying costs reflecting primarily the costs of capital tied up in extra inventory, and secondarily the incremental cost of insurance, handling, and storage. The second markup, at a three percent rate, covers dealer carrying costs reflecting the cost of capital tied up in extra inventory. These markups were discussed in more detail in section A of this chapter. Fixed costs were amortized at a seven percent rate and recovered over a five year period.

2. Technology Packages for Compliance with the 2008 Model Year Heavy-Duty Gasoline Standards

The various technologies that could be used to comply with the proposed regulations were discussed in Chapter 3. We expect that the technology mixes used to meet the California LEV-II standards, and our Tier 2 standards, fairly accurately represent those that will be used to comply with the 2008 heavy-duty gasoline standards. Thus, in developing costs for the technology packages we expect to be used, we started with the technology packages assumed to be implemented on HD gasoline vehicles and engines to meet the 2005 standards. Table 5.B-1 shows both the expected 2005 technology packages, the baseline for this analysis, and the expected 2008 technology packages for both complete and incomplete gasoline vehicles. The expected technologies for 2008 are consistent between vehicles and engines; we make this assumption based on our belief that the standards for vehicles and engines are equivalently stringent.

This table only shows the technologies which are expected to change in some way or to be applied in different percentages to meet the 2008 standards. A technology like sequential multi-port fuel injection, while important to meeting the new standards, is expected on 100 percent of the 2005 vehicles and engines, and its design is not expected to fundamentally change for 2008. As a result, we expect no incremental changes or costs associated with that technology, and it is not included in the table. However, the table does contain technologies we believe will be more widely implemented, but which have no associated costs for their implementation. One such example, spark retard on engine start up, is expected to be more widely implemented for the 2008 standards, but there are no costs associated with implementing that technology. Such technologies are included in these tables for completeness, but do not appear in later tables showing the incremental costs associated with the 2008 standards.

Table V.B-1. 2005 (Phase 1) and Expected 2008 (Phase 2) Technology Packages for Heavy-Duty Gasoline Vehicles excluding Medium-Duty Passenger Vehicles

Technology	*2005 Complete Vehicles*	*2005 Incomplete Vehicles (Engine-Based)*	*2008 Expected for Complete and Incomplete Vehicles*
Catalysts[A]	13% single underfloor 50% dual underfloor 37% dual close-coupled with dual underfloor	13% single underfloor 87% dual underfloor	50% dual underfloor 50% dual close-coupled with dual underfloor
Oxygen sensors[B]	13% dual heated 87% four heated	13% triple heated 87% four heated	100% four heated with two being fast light-off
EGR	85% -- All electronic	85% -- All electronic	100% -- All electronic
Adaptive learning	80%	80%	100%
Heat managed exhaust[C]	40%	0%	80%[D]
Secondary air injection with closed-loop control	30%	50%	50%
Spark retard at start-up	0%	0%	100%

[A] In addition to the change in catalyst configurations shown, we expect that catalyst washcoat and precious metal compositions and loadings will change.

[B] The estimated breakdown for 2005 reflects OBD requirements for all HDGEs. However, OBD is only required on HDGEs under 14,000 lbs GVWR (approximately 60 percent of HDGEs).

[C] May include air gaps, thin walls, low thermal capacity manifold, insulation, etc.

[D] 100 percent of those having dual underfloor catalysts, and 60 percent of those having dual close-coupled w/ dual underfloor catalysts.

3. Technology/Hardware Costs for Gasoline Vehicles and Engines

The following sections present the costs of the technologies we expect will be used to comply with the 2008 standards. Because most heavy-duty gasoline manufacturers offer more than one engine for their heavy-duty gasoline product line, cost estimates have been developed for a standard engine size and a larger engine size.

a. Improved Catalysts and Catalyst Systems

Improvements in catalyst systems fall into two broad categories: changes in catalyst system configuration and changes in the catalyst precious metal and washcoat compositions and loadings. In addition to estimating costs for these improvements, we have estimated the increased costs of substrates and packaging (cans) for the improved catalysts.

i. Changes in Catalyst Configurations

For heavy-duty gasoline vehicles and engines, we expect there to be generally three catalyst configurations for meeting the 2005 and 2008 standards -- the single underfloor, the dual underfloor, and the dual close-coupled combined with the dual underfloor. With the single underfloor catalyst system, the exhaust streams from both banks of engine cylinders “Y” into a single catalyst. With the dual underfloor catalyst system, each bank of engine cylinders exhausts into its own catalyst. With a dual close-coupled catalyst system, each bank of engine cylinders exhausts directly into a small, often called “pipe,” catalyst, and then into a dual underfloor main catalyst system.

For 2005, we estimate that: 13 percent of vehicles will employ a single underfloor catalyst; 50 percent of vehicles will employ dual underfloor catalysts; and, 37 percent of vehicles will employ dual close-coupled with dual underfloor catalysts. For 2008, we expect that 50 percent of vehicles will employ dual underfloor with the remaining 50 percent employing dual close-coupled catalysts with a dual underfloor. For engine based systems in 2005, we estimate that: 13 percent of engines will employ a single underfloor catalyst; and, 87 percent will employ dual underfloor catalysts. For 2008, we expect that engines will employ the same configurations as outlined above for vehicles. We believe these vehicle and engine catalyst configuration estimates to be reasonable given the estimated catalyst configuration employment in our Tier 2 analysis for MDPVs (80 percent with dual close-coupled and either single or dual underfloor configurations), and some previously done Arcadis estimates for standards similar to our 2008 standards.[27]

ii. Changes in Catalyst Volumes and Precious Metal Loadings

The catalyst configuration changes and associated costs discussed above do not include changes in the precious metal and washcoat compositions and loadings. Gasoline vehicle catalysts have typically used some combination of platinum (Pt), palladium (Pd) and rhodium (Rh). These precious metals, or platinum group metals (PGM), account for a significant portion of the catalyst cost. Historically, a Pt/Rh combination has been used, but Pd has been seeing increased use in recent years. Pd is more thermally stable than Pt and Rh, which makes it a good choice for close-coupled catalysts, which are typically 100 percent Pd, where much higher temperatures are experienced. For 2005, we estimate a Pt/Pd/Rh ratio of 0/10/1 applied at a PGM loading of 4 grams/liter (g/L) for vehicles and 4.5 g/L for engines. For 2008, we estimate that the ratio will change to 1/14/1, consistent with Tier 2, at a loading of 5 g/L.[28]

We have also estimated that catalyst volumes will increase. For 2005, we assume catalyst volumes will be 4.8 liters for the standard engines and 5.8 liters for the larger engines. Because the 2008 standards are more stringent, we expect that catalyst volumes will need to increase to 5.2 liters and 6.4 liters, respectively. In our Tier 2 analysis, we assumed that catalyst volumes would increase to equal engine displacement volume; however, we assumed no increase in precious metal loading.[e] While the catalyst volumes we are assuming for 2008 may be low for some applications and high for others (2000 model year certified engine displacements ranged from 4.2 L to 8.0 L), we believe that we have chosen the appropriate middle ground of likely catalyst volumes.

The estimated costs associated with increased use of precious metals are summarized in Table V.B-2.

[e] We assume a higher precious metal loading than our recent Tier 2 analysis because heavy-duty vehicles, by definition, undergo more rigorous operation during normal use. Therefore, more precious metals would probably be required to maintain acceptable emissions durability characteristics.

Table V.B-2. Costs Associated with the Increased Use of Precious Metals

Vehicles

	Projected 2005 Catalyst Volume (L)	Projected 2008 Catalyst Volume (L)	2005 Catalyst Loading (g/L)	2008 Catslyst Loading (g/L)	2005 Pt/Pd/Rh	2008 Pt/Pd/Rh	2005 Pt (g)	2005 Pd (g)	2005 Rh (g)	2008 Pt (g)	2008 Pd (g)	2008 Rh (g)	Increased Pt (g)	Increased Pd (g)	Increased Rh (g)	2005 PGM Cost ($)	2008 PGM Cost ($)
Standard Engine	4.8	5.2	4	5	0/10/1	1/14/1	0.000	17.455	1.745	1.625	22.750	1.625	1.625	5.295	-0.120	267.60	352.17
Larger Engine	5.8	6.4	4	5	0/10/1	1/14/1	0.000	21.091	2.109	2.000	28.000	2.000	2.000	6.909	-0.109	323.35	433.44

Engines

	Projected 2005 Catalyst Volume (L)	Projected 2008 Catalyst Volume (L)	2005 Catalyst Loading (g/L)	2008 Catslyst Loading (g/L)	2005 Pt/Pd/Rh	2008 Pt/Pd/Rh	2005 Pt (g)	2005 Pd (g)	2005 Rh (g)	2008 Pt (g)	2008 Pd (g)	2008 Rh (g)	Increased Pt (g)	Increased Pd (g)	Increased Rh (g)	2005 PGM Cost ($)	2008 PGM Cost ($)
Standard Engine	4.8	5.2	4.5	5	0/10/1	1/14/1	0.000	19.636	1.964	1.625	22.750	1.625	1.625	3.114	-0.339	301.05	352.17
Larger Engine	5.8	6.4	4.5	5	0/10/1	1/14/1	0.000	23.727	2.373	2.000	28.000	2.000	2.000	4.273	-0.373	363.77	433.44

Precious Metal Costs (9/29/99)

	$/Troy Oz	$/gram
Platinum	412	13.25
Paladium	390	12.54
Rhodium	868	27.91

iii. Changes in Catalyst Washcoat

In addition to the changes to precious metals just discussed, we expect that the 2008 standards will also result in changes to the catalyst washcoat compositions and loadings. Current washcoats are typically a combination of a cerium oxide blend (ceria) and aluminum oxide (alumina). Current ratios of these two components range from 75 percent ceria/25 percent alumina to 100 percent alumina. Of the two common washcoat components, ceria is more thermally stable and, thus, is expected in higher concentrations in close-coupled catalysts. We assume that a 75/25 ratio of ceria to alumina will be used to comply with the 2005 vehicle-based standards and that an even higher 80/20 ratio of ceria to alumina will be used to comply with the engine-based standards. For 2008, we are assuming that all washcoats will use an 80/20 ratio of ceria to alumina.

Current washcoat loadings range from 160 to 220 g/L of catalyst substrate volume. For 2005, we assume an average loading of 190 g/L for vehicle-based systems, and 220 g/L for engine-based systems. For 2008, we are assuming a loading of 220 g/L for all substrates. In addition, we expect that a new technique of layering the washcoat and precious metals will be employed. Currently, the precious metals and washcoat are applied to the catalyst substrate in a single slurry. Under the layering approach, there is a separate slurry for each precious metal, with the second slurry being applied after the first dries. This process allows for more reaction surface area, resulting in a more efficient catalyst.

iv. Catalyst Substrates

The substrate that the precious metals and washcoat are affixed to are typically ceramic substrates of 400 cells per inch. Increasing efforts are going into developing metallic substrates, which offer better temperature and vibration stability, as well as requiring less precious metal loading to achieve the same emission benefits. Since the increased costs of the metal substrates will tend to cancel out any savings in precious metal costs, we assumed that the current ceramic substrate would continue to be used to comply with the 2005 standards. We are assuming the same for the 2008 standards. The following linear relationship has been shown to be accurate for ceramic substrates sized from 0.5 L to 4 L:[29]

$$C = \$4.67V + \$1.50$$

where:

C = cost to the vehicle manufacturer from the substrate supplier
V = substrate volume in liters

We are including an increased substrate cost due to the larger expected catalyst volumes; larger catalysts will need larger substrates. Generally, catalyst substrates for heavy-duty gasoline vehicles and engines are manufactured in bricks no larger than 2.5 L, with a catalyst of greater than 2.5 L being comprised of more than one brick.

v. Catalyst Packaging

The final cost component of the catalyst system is the catalyst can. The catalyst substrate is typically packaged in a can made of 409 stainless steel and around 0.12 centimeters thick (18 gauge). The increased catalyst volumes expected for 2008 model year catalysts will result in more stainless steel and, therefore, more cost. The cost of the can is a very small portion of the overall catalyst cost.

vi. Summary of Catalyst Costs

Table V.B-3 shows our estimates of the total catalyst system cost for each of the three configurations previously discussed for the 2005 and 2008 standards. This table includes catalyst costs for standard size and larger size engines for applications certified to the vehicle or the engine standards. The Pt/Pd/Rh costs are taken from Table V.B-2 and do not have a supplier markup applied because we have been informed that the vehicle manufacturer purchases the precious metals and provides them to their catalyst supplier. Included in the table are incremental costs for ease of comparison. No costs are shown for a single underfloor catalyst system for 2008 because we do not expect any such applications in 2008.

Table V.B-3. Costs Associated with Various Catalyst Configurations

Single Underfloor Catalyst System

	Complete Vehicles				Incomplete Vehicles			
	2005 Vehicle		2008 Vehicle		2005 Engine		2008 Engine	
	Standard	Larger	Standard	Larger	Standard	Larger	Standard	Larger
Catalyst Volume (liters)	4.8	5.8	n/a	n/a	4.8	5.8	n/a	n/a
Substrate*	$25	$31			$25	$31		
Washcoat**	$18	$22			$22	$26		
Pt/Pd/Rh	$268	$323			$301	$364		
Can (18 gauge 409 SS)**	$5	$5			$5	$5		
Total Material Cost	$321	$387			$358	$431		
Labor	$4	$4			$6	$6		
Labor Overhead @ 40%	$2	$2			$2	$2		
Supplier Markup @ 29% ***	$8	$9			$10	$11		
Manufacturer Cost	$335	$402			$377	$451		
Manufacturer Carrying Cost @ 4%	$13	$16			$15	$18		
Total Cost to Dealer	**$348**	**$418**			**$392**	**$469**		
Incremental Cost			n/a	n/a			n/a	n/a

Dual Underfloor Catalyst System

	Complete Vehicles				Incomplete Vehicles			
	2005 Vehicle		2008 Vehicle		2005 Engine		2008 Engine	
	Standard	Larger	Standard	Larger	Standard	Larger	Standard	Larger
Catalyst Volume (liters)	4.8	5.8	5.2	6.4	4.8	5.8	5.2	6.4
Substrate*	$25	$31	$27	$34	$25	$31	$27	$34
Washcoat**	$18	$22	$24	$29	$22	$26	$24	$29
Pt/Pd/Rh	$268	$323	$352	$433	$301	$364	$352	$433
Can (18 gauge 409 SS)**	$5	$6	$6	$7	$5	$6	$6	$7
Total Material Cost	$321	$388	$415	$510	$358	$432	$415	$510
Labor	$7	$8	$11	$13	$11	$12	$11	$13
Labor Overhead @ 40%	$3	$3	$4	$5	$4	$5	$4	$5
Supplier Markup @ 29% ***	$10	$11	$13	$16	$12	$14	$13	$16
Manufacturer Cost	$340	$410	$443	$543	$386	$463	$443	$543
Manufacturer Carrying Cost @ 4%	$14	$16	$18	$22	$15	$19	$18	$22
Total Cost to Dealer	**$354**	**$427**	**$461**	**$565**	**$401**	**$482**	**$461**	**$565**
Incremental Cost			$107	$139			$60	$84

Dual Close-coupled with Dual Underfloor Catalyst System

	Complete Vehicles				Incomplete Vehicles			
	2005 Vehicle		2008 Vehicle		2005 Engine		2008 Engine	
	Standard	Larger	Standard	Larger	Standard	Larger	Standard	Larger
Catalyst Volume (liters)	4.8	5.8	5.2	6.4	4.8	5.8	5.2	6.4
Substrate****	$28	$33	$30	$36	$28	$33	$30	$36
Washcoat**	$19	$23	$24	$29	$19	$23	$24	$29
Pt/Pd/Rh	$268	$323	$352	$433	$301	$364	$352	$433
Can (18 gauge 409 SS)**	$6	$7	$7	$8	$7	$8	$7	$8
Total Material Cost	$325	$392	$418	$513	$360	$434	$418	$513
Labor	$14	$15	$18	$20	$18	$20	$18	$20
Labor Overhead @ 40%	$6	$6	$7	$8	$7	$8	$7	$8
Supplier Markup @ 29% ***	$13	$15	$16	$19	$15	$17	$16	$19
Manufacturer Cost	$358	$428	$460	$560	$400	$479	$460	$560
Manufacturer Carrying Cost @ 4%	$14	$17	$18	$22	$16	$19	$18	$22
Total Cost to Dealer	**$372**	**$445**	**$478**	**$582**	**$416**	**$498**	**$478**	**$582**
Incremental Cost			$106	$137			$62	$84

*2.5 L bricks; use C=$4.67V+$1.50 (Arcadis, 9/30/99) with the $1.50 applied per 2.5L brick (Note: C is cost to mfr, thus not marked up in tables).
**Baseline from 2005 FRM RIA; 2008 from Arcadis 9/30/98.
***Not applied to precious metals or Substrate (substrate costs already include supplier markup).
****From 2005 FRM RIA and Arcadis, 9/30/98.

b. Oxygen Sensors

Largely because we expect catalyst configurations to change, we expect oxygen sensor usage to change. Oxygen sensors are used both for fuel control and for OBD catalyst monitoring. Therefore, different catalyst configurations would likely result in different oxygen sensor usage. For 2005, we assume that 13 percent of heavy-duty gasoline vehicles and engines will employ dual heated oxygen sensors, and 87 percent will employ four heated oxygen sensors. For 2008, we assume that all vehicles and engines will use four heated oxygen sensors, with two of those being fast light-off sensors for better cold start performance. We have estimated the cost of a heated oxygen sensor at $20 per sensor, and a fast light-off sensor at $28 per sensor.

c. Exhaust Gas Recirculation (EGR)

Electronically controlled EGR is currently used on about 85 percent of non-California gasoline heavy-duty vehicles. The percentage of the fleet with EGR is not expected to change as a result of the 2005 standards. For 2008, we assume that 100 percent of vehicles and engines will use electronically controlled EGR. In addition, some minor changes in control algorithms may be necessary to improve upon EGR performance. These changes are expected to cost from $5 to $12 per vehicle. For this analysis, we have used a cost of $10 per vehicle, applied only to those 15 percent adding EGR for 2008.

d. Secondary Air Injection with Closed Loop Control

The hardware cost for vehicles which use secondary air injection to reduce HC and CO emissions is estimated to be about $65 per vehicle. For 2005, we estimate a secondary air injection usage rate of 30 percent on vehicles and 50 percent on engines. For 2008, we estimate that 50 percent of vehicles will use secondary air injection, while the percentage of engines using it will remain at 50 percent.

e. Exhaust Systems

We expect that heat managed exhaust systems will be used on some applications to improve catalyst light-off time. Heat managed exhaust systems can include any combination of thin walled components or otherwise low thermal-capacity components, air gapped components, insulation, etc. We estimate that such systems will cost $40 per vehicle when they are used. For 2005, we estimate that they will be used on 40 percent of the vehicles, and none of the engines. For 2008, we estimate that they will be used on 60 percent of vehicles and engines having a dual close-coupled with a dual underfloor catalyst system, and 100 percent of vehicles and engines having only a dual underfloor catalyst system.

f. Evaporative Emission Control Systems

There are two approaches to reducing evaporative emissions for a given fuel. One is to minimize the potential for permeation and leakage by reducing the number of hoses, fittings and connections. The second is to use less permeable hoses and lower loss fittings and connections. Manufacturers are already employing both approaches. The 2008 evaporative emission standards will not require the development of new materials or, in many cases, even the new application of existing materials. Low permeability materials and low loss connections and seals are already used to varying degrees on current vehicles.

In our proposal, we estimated the cost associated with our new evaporative standards at $4 per vehicle. However, we received comments that our $4 per vehicle cost was not appropriate for heavy-duty gasoline vehicles. Those comments suggested the cost would be as high as $32 to $45 per vehicle, with claims that a new canister array, a returnless fuel system, an upgrade of fuel system materials, and possible air inlet control measures would be needed.

The $4 estimate used in our proposal was developed for light-duty applications under our Tier 2 cost analysis.[30] Given that the Tier 2 estimate was for light-duty applications, it may represent an under estimate of the cost for heavy-duty applications. Despite the fact that most heavy-duty gasoline vehicles currently can meet the emission levels being finalized, we believe that manufacturers will improve upon their designs so as to improve upon compliance margins.

We also believe that the $32 to $45 cost estimate supplied via comment represents a worst case estimate rather than an average cost that can be applied across the HD gasoline fleet. Therefore, we have increased our estimated cost from $4 to $21 to represent a conservative estimate of the typical cost. The $21 estimate is a middle ground estimate appropriate for application to the entire heavy-duty gasoline fleet. This seems reasonable considering the $4 cost at the lighter end of the range where vehicles are similar to the Tier 2 MDPVs, and the $32 to $45 cost for vehicles at the heavier end of the range where larger fuel tanks and longer fuel lines present more challenge. This $21 cost is applied to all heavy-duty gasoline vehicles and engines for the purpose of estimating the overall cost of the new standards regardless of their current emission levels.

g. Summary of Technology/Hardware Costs

The costs associated with technology, or hardware, are summarized in Table V.B-4.

Table V.B-4. Summary of Hardware Costs for the Proposed 2007 Heavy-Duty Gasoline Standards

	Complete Vehicles						Incomplete Vehicles					
	2005 Vehicle		2008 Vehicle		Increment		2005 Engine		2008 Engine		Increment	
	Standard System	Larger System	Standard System	Larger System	Standard System	Larger System	Standard System	Larger System	Standard System	Larger System	Standard System	Larger System
Catalyst Costs	$360	$432	$470	$574	$110	$141	$400	$480	$470	$574	$70	$94
Oxygen Sensors	$75	$75	$96	$96	$21	$21	$77	$77	$96	$96	$19	$19
EGR	$9	$9	$10	$10	$2	$2	$9	$9	$10	$10	$2	$2
Heat Managed Exhaust*	$16	$16	$32	$32	$16	$16	$0	$0	$32	$32	$32	$32
Secondary Air Injection with Closed Loop Control	$20	$20	$33	$33	$13	$13	$33	$33	$33	$33	$0	$0
Evap System Improvements	$0	$0	$21	$21	$21	$21	$0	$0	$21	$21	$21	$21
Total Dealer Cost	$479	$551	$661	$765	$183	$214	$518	$598	$661	$765	$143	$167
Dealer Carrying Cost @ 3%	$14	$17	$20	$23			$16	$18	$20	$23		
Total Cost to the Consumer	$493	$568	$681	$788			$534	$616	$681	$788		
Increased Cost to the Consumer					**$188**	**$220**					**$147**	**$172**

*May include air gaps, thin walls, low thermal capacity manifold, insulation, etc.
Note: Some values may not add up precisely due to rounding.

As Table V.B-4 shows, the incremental technology costs for heavy-duty gasoline vehicles and engines associated with the 2008 standards are $188 and $220 for standard and large sized engines in vehicle-based applications, respectively, and $147 and $172 for standard and large sized engines in engine-based applications, respectively.

Weighting these costs assuming a standard/large split of 75/25 percent, gives incremental costs of $196 for complete vehicles and $153 for incomplete vehicles. For the long-term, there are factors we believe are likely to reduce the costs to manufacturers. As noted below, we project fixed costs to be recovered by manufacturers during the first five years of production, after which they would expire. For variable 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. These effects are often described as the manufacturing learning curve as described in Chapter V.A.6 of this Regulatory Impact Analysis.

We applied a p value of 80 percent in this analysis. Using one year as the base unit of production, the first doubling would occur at the start of the third model year of production. Beyond that time, we did not incorporate further cost reductions due to the learning curve. This differs from the heavy-duty diesel cost analysis where we did apply the learning curve beyond the third year. We applied the learning curve reduction only once for gasoline because we anticipate that, for the most part, the 2008 heavy-duty standards would be met through improvements to existing technologies rather than through the use of new technologies. With existing technologies, there would be less opportunity for lowering production costs.

In addition, we did not apply the learning curve to the catalyst precious metal costs due to the uncertainty of future precious metal prices. Although manufacturers may be able to reduce the use of precious metals through factors consistent with the application of the learning curve, the future price of precious metals is highly uncertain. Any savings due to a reduction in the amount of precious metals used for a catalyst system could be overcome by increased precious metal unit costs. Also, we have not applied the learning curve to evaporative emission control system costs.

Therefore, as a result of the learning curve, the variable costs per vehicle, minus the precious metal costs, would decrease by 20 percent beginning in the 2010 model year. Thereafter, the incremental technology costs would fall to $179 and $138 for vehicles and engines, respectively.

4. Heavy-Duty Gasoline Fixed Costs

The fixed costs are broken into four main components: research and development, tooling, certification, and in-use testing. These costs are discussed individually in the following sections.

a. R&D and Tooling Costs

The 2008 vehicle-based standards will essentially require the application of California LEV-II and Tier 2 technology to heavy-duty gasoline vehicles nationally. Since this technology is being developed in response to those rules, we are assuming that considerable carry-across will occur from those R&D efforts to the heavy-duty gasoline systems. R&D primarily includes engineering staff time and development vehicles. A large part of the research effort will be evaluating and selecting the appropriate mix of emission control components and optimizing those components into a system capable of meeting the 2008 standards. It also includes engine modifications where necessary and air/fuel ratio calibration work. Manufacturers will take differing approaches in their research programs. In our Tier 2 analysis, we assumed an R&D cost of $5 million per vehicle line estimating that this would cover about 25 engineering staff person years and about 20 development vehicles.[f] We estimated such a large R&D effort because calibration and system optimization was expected to be a critical part of the effort to meet the Tier 2 standards. However, we believe those R&D costs are likely overstated for purposes here because the projection ignores the carryover of knowledge from the first vehicle lines designed to meet the standard to others phased-in later. For this heavy-duty gasoline analysis, we assume an R&D cost of $2.5 million per line due to the carryover from Tier 2 and LEV II R&D efforts.

According to 2000 model year certification data, there is one engine family certified as an incomplete vehicle federally with no corresponding engine certified for sale in California. We have assumed that engine will require R&D efforts to comply with today's proposed standards. We have also assumed that four other engines (those having six liters or more displacement typically used in larger applications) currently being certified to engine standards will continue to be so certified and will require R&D efforts to comply with today's engine standards. That gives four more engines requiring R&D efforts, for a total of five engines to which we have applied the $2.5 million R&D cost.

In our Tier 2 analysis and our proposal, we estimated tooling costs at $2 million per line. Tooling costs include facilities modifications necessary to produce and assemble components and vehicles meeting the new standards. We believe that this is a reasonable estimate based on engineering judgement and review of previous estimates of tooling costs for emissions control components.[31] We have applied tooling costs only to those engines requiring R&D efforts.

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[f] This estimate is based on staff cost of $60 per hour and development vehicle cost of $100,000 per vehicle line.

R&D costs are spread out evenly over the three year period prior to the first year of implementation and grown at a seven percent rate. Tooling costs are assumed to occur one year prior to implementation and are grown for one year at a seven percent rate. These costs are then amortized over a five year period following implementation, again at a seven percent rate. This results in R&D and tooling costs of just over $9 per complete vehicle and $23 per incomplete vehicle. The costs are higher for the incomplete vehicles because of the lower sales over which to spread the same total costs as estimated for complete vehicles. These costs become zero five years after implementation because we assume the costs will have been recovered.

b. Certification Costs

Manufacturers incur an annual cost as part of certification and compliance and would incur those costs without any change to the standards. However, we allow manufacturers to carry-over some data generated for certification when vehicles are not significantly changed from one model year to the next. This test data is generated to demonstrate vehicle emissions levels and emissions durability. Due to the new standards, such data will have to be generated for the new 2008 model year vehicles rather than being carried-over from previous model years. Therefore, we believe it is appropriate to include the cost of generating new emissions test and durability data. We have estimated certification costs at $30,000 per engine family.[32] This estimate does not account for the ability of manufacturers, in most cases, to carry-over certification data from California certified systems. Such a practice would lower certification costs.

We have applied the certification cost to the 17 complete and 26 incomplete engine families, the number certified for the 2000 model year. Certification costs would be incurred, on average, one year before the start of production. Thus, this cost is increased at a rate of seven percent for one year and applied to the appropriate vehicle certifications and engine certifications. The costs are then amortized over five years and divided by the appropriate complete and incomplete sales projections. This results in projected per-vehicle certification costs of $0.42 for complete vehicle configurations and $1.59 for incomplete vehicle configurations during the first five years of the program. After five years, the certification costs become zero as manufacturers fall into their normal practice of carrying-over data from one year to the next.

5. Summary of Heavy-Duty Gasoline Costs

Table V.B-5 contains a summary of per-vehicle costs associated with the 2008 standards for heavy-duty gasoline vehicles and engines. The hardware cost components include a part or emission control system supplier markup of 29 percent, and both manufacturer and dealer carrying costs of four percent and three percent, respectively. The costs are presented as incremental cost increases from the 2005 system costs.

Table V.B-5. Summary of Incremental Costs to Meet the 2008 Heavy-Duty Gasoline Emission Standards

		Complete Vehicles	*Incomplete Vehicles*	*HDGVs*
Near Term	Technology/Hardware	$196	$153	$184
	Fixed Costs	$10	$25	$14
	Incremental Cost	**$206**	**$178**	**$198**
Long Term	Technology/Hardware	$179	$138	$167
	Fixed Costs	$0	$0	$0
	Incremental Cost	**$179**	**$138**	**$167**

6. Total Nationwide Costs for 2008 Heavy-Duty Gasoline Vehicles

The above analyses developed incremental per vehicle manufacturer and consumer cost estimates for heavy-duty gasoline vehicles designed to the new Phase 2 gasoline standards. With data for the current size and characteristics of the vehicle fleet and projections for the future, we have translated these per vehicle costs into estimated total annualized costs to the nation for the new Phase 2 gasoline standards. Table V.B-6 presents the results of this analysis.

To prepare these estimates, we projected sales for heavy-duty gasoline vehicles. We estimated current vehicle sales based on 1996 sales data submitted by vehicle manufacturers as part of certification. These sales correlated reasonably well with other available sales information. We assumed a mix of 71 percent complete vehicles and 29 percent incomplete vehicles based on these sales data, excluding an estimated 70,000 units counted in the Tier 2 analysis as medium-duty passenger vehicles. California sales were excluded from this analysis because California emissions standards apply to those vehicles. We have projected vehicle sales to grow two percent from 1996 through 2007, then at a constant number of vehicles (two percent of 1996 sales) for each year thereafter. Table V.B-6 contains those sales projections.

Table V.B-6. Estimated Annualized Nationwide Vehicle Costs Associated with the 2008 Heavy-Duty Gasoline Emission Standards

Year	Projected Sales	Fixed Costs	Fraction of Fleet Complying	Variable Costs	Operating Costs	Total Cost	Per Vehicle Cost
2007	424,560	$0	0%	$0	$0	$0	$0
2008	431,520	$6,213,290	50%	$39,635,728	$0	$45,849,018	$213
2009	438,480	$6,213,290	100%	$73,362,727	$0	$79,576,017	$181
2010	445,440	$6,213,290	100%	$74,527,215	$0	$80,740,505	$181
2011	452,400	$6,213,290	100%	$75,691,703	$0	$81,904,993	$181
2012	459,360	$6,213,290	100%	$76,856,190	$0	$83,069,481	$181
2013	466,320	$0	100%	$78,020,678	$0	$78,020,678	$167
2014	473,280	$0	100%	$79,185,166	$0	$79,185,166	$167
2015	480,240	$0	100%	$80,349,654	$0	$80,349,654	$167
2016	487,200	$0	100%	$81,514,141	$0	$81,514,141	$167
2017	494,160	$0	100%	$82,678,629	$0	$82,678,629	$167
2018	501,120	$0	100%	$83,843,117	$0	$83,843,117	$167
2019	508,080	$0	100%	$85,007,604	$0	$85,007,604	$167
2020	515,040	$0	100%	$86,172,092	$0	$86,172,092	$167
2021	522,000	$0	100%	$87,336,580	$0	$87,336,580	$167
2022	528,960	$0	100%	$88,501,068	$0	$88,501,068	$167
2023	535,920	$0	100%	$89,665,555	$0	$89,665,555	$167
2024	542,880	$0	100%	$90,830,043	$0	$90,830,043	$167
2025	549,840	$0	100%	$91,994,531	$0	$91,994,531	$167
2026	556,800	$0	100%	$93,159,019	$0	$93,159,019	$167
2027	563,760	$0	100%	$94,323,506	$0	$94,323,506	$167
2028	570,720	$0	100%	$95,487,994	$0	$95,487,994	$167
2029	577,680	$0	100%	$96,652,482	$0	$96,652,482	$167
2030	584,640	$0	100%	$97,816,970	$0	$97,816,970	$167
2031	591,600	$0	100%	$98,981,457	$0	$98,981,457	$167
2032	598,560	$0	100%	$100,145,945	$0	$100,145,945	$167
2033	605,520	$0	100%	$101,310,433	$0	$101,310,433	$167
2034	612,480	$0	100%	$102,474,920	$0	$102,474,920	$167
2035	619,440	$0	100%	$103,639,408	$0	$103,639,408	$167

As shown in Table V.B-6, we have projected a total cost starting at $46 million in 2008 and peaking at $83 million in 2012. In 2013, the costs decrease due to the elimination of fixed costs. Thereafter, costs gradually increase with projected sales. Operating costs are $0 because the technologies expected should have no impact on fuel economy or maintenance costs. The calculated total costs represent a combined estimate of fixed costs, as they are allocated over fleet sales during the first five years of sale, and variable costs assessed at the point of sale. These costs include exhaust and improved evaporative control systems. These estimates do not include costs due to improved fuel quality, which were presented in the Tier 2 Regulatory Impact Analysis for gasoline.[33]

Table V.B-7 shows the non-annualized costs.

Table V.B-7. Estimated Non-Annualized Nationwide Vehicle Costs Associated with the 2008 Heavy-Duty Gasoline Emission Standards

Year	Projected Sales	Fixed Costs	Fraction of Fleet Complying	Variable Costs	Operating Costs	Total Cost
2004	403,680	$0	0%	$0	$0	$0
2005	410,640	$4,166,667	0%	$0	$0	$4,166,667
2006	417,600	$4,166,667	0%	$0	$0	$4,166,667
2007	424,560	$14,946,667	0%	$0	$0	$14,946,667
2008	431,520	$0	50%	$39,635,728	$0	$39,635,728
2009	438,480	$0	100%	$73,362,727	$0	$73,362,727
2010	445,440	$0	100%	$74,527,215	$0	$74,527,215
2011	452,400	$0	100%	$75,691,703	$0	$75,691,703
2012	459,360	$0	100%	$76,856,190	$0	$76,856,190
2013	466,320	$0	100%	$78,020,678	$0	$78,020,678
2014	473,280	$0	100%	$79,185,166	$0	$79,185,166
2015	480,240	$0	100%	$80,349,654	$0	$80,349,654
2016	487,200	$0	100%	$81,514,141	$0	$81,514,141
2017	494,160	$0	100%	$82,678,629	$0	$82,678,629
2018	501,120	$0	100%	$83,843,117	$0	$83,843,117
2019	508,080	$0	100%	$85,007,604	$0	$85,007,604
2020	515,040	$0	100%	$86,172,092	$0	$86,172,092
2021	522,000	$0	100%	$87,336,580	$0	$87,336,580
2022	528,960	$0	100%	$88,501,068	$0	$88,501,068
2023	535,920	$0	100%	$89,665,555	$0	$89,665,555
2024	542,880	$0	100%	$90,830,043	$0	$90,830,043
2025	549,840	$0	100%	$91,994,531	$0	$91,994,531
2026	556,800	$0	100%	$93,159,019	$0	$93,159,019
2027	563,760	$0	100%	$94,323,506	$0	$94,323,506
2028	570,720	$0	100%	$95,487,994	$0	$95,487,994
2029	577,680	$0	100%	$96,652,482	$0	$96,652,482
2030	584,640	$0	100%	$97,816,970	$0	$97,816,970
2031	591,600	$0	100%	$98,981,457	$0	$98,981,457
2032	598,560	$0	100%	$100,145,945	$0	$100,145,945
2033	605,520	$0	100%	$101,310,433	$0	$101,310,433
2034	612,480	$0	100%	$102,474,920	$0	$102,474,920
2035	619,440	$0	100%	$103,639,408	$0	$103,639,408

C. Diesel Fuel Costs

In this section, we first lay out the methodology for our analysis of the cost of desulfurizing highway diesel fuel. Then we present the estimated cost of desulfurizing highway diesel fuel.

1. Methodology

a. Overview

For the proposed rule, we estimated the cost of desulfurizing highway diesel fuel to meet a 15 ppm cap sulfur standard based on a characteristic refinery, which was sized to represent the average cost for all U.S. refineries. Although we felt confident in the cost estimates made with this model, the analysis did not allow us to adequately address certain issues, particularly the comments which we received concerning the future supply of highway diesel fuel. For this final rule, we expanded upon our analysis to allow us to better understand the range of situations faced by refiners to supply highway diesel fuel. This section presents an overview of our expanded cost analysis.

Our cost estimate for desulfurizing diesel fuel is based on hydrotreating process operations and capital cost information received from two licensors of conventional distillate[g] desulfurization technology. In addition, information obtained from two other vendors of diesel desulfurization technology further corroborated the information provided by the first two vendors. The costs for desulfurizing diesel fuel were estimated for each refinery in the country which was producing highway diesel fuel during 1998 and 1999. Each refinery's production volumes were projected to 2006 using a ratio of the projected consumption of highway diesel fuel in 2006 by EIA versus the production in 1998 and 1999. We presume that each refinery producing highway diesel fuel starts with a highway diesel fuel sulfur level of about 340 ppm and reduces it to between 5 to 10 ppm, or 7 ppm on average. We believe that refiners would have to desulfurize their diesel fuel to about 7 ppm to reliably and continually meet the proposed 15 ppm cap standard. Construction and operating cost factors and utility costs for each refinery are based on values calculated for each PADD and are applied to all the refineries operating in that PADD. For each refinery we estimated the fraction of straight run distillate, light cycle oil (LCO), and other cracked stocks (coker, visbreaker, thermal cracked) in the highway diesel fuel, and the cost to desulfurize each of those stocks. The average desulfurization cost for each refinery was based on the volume-weighted average of desulfurizing each of those blendstocks. We based our cost estimate on the premise that the refining industry will be able to revamp 80 percent of the

[g] Distillate refers to a broad category of fuels falling into a specific boiling range. Distillate fuels have a heavier molecular weight and therefore boil at higher temperatures than gasoline. Distillate includes diesel fuel, jet fuels, kerosene and home heating oil.

existing diesel hydrotreater capacity, while the other 20 percent will have to install brand new "grassroots" units. Since we do not know which refineries would install revamps units and which would install grassroots units, we calculated the revamp and grassroots cost for each refinery, and based 80 percent of the cost on the revamped cost, and 20 percent on the grassroots cost. For determining the grassroots cost of a refinery currently producing highway diesel fuel, we used the operating cost of a revamped unit and the capital cost of a grassroots unit. Using the operating cost of a revamped unit is appropriate because that refinery is incurring operating cost now for meeting the current 500 ppm sulfur highway diesel fuel standard.

The final rule provides the refining industry a temporary compliance option which refiners them to continue selling up to about 20 percent of the highway diesel pool at this higher sulfur level until 2010, at which point all highway diesel fuel must meet the 15 ppm cap sulfur standard. We estimated the cost of refiners using this option based on the assumption that the refineries which can meet the 15ppm cap sulfur standard at the lowest cost will meet the requirements in 2006. The balance of refineries are presumed hold off making their investments to meet the 15 ppm sulfur standard until 2010.

We received a number of comments from the refining industry which suggested that some refiners may choose to partially or completely leave the highway diesel fuel market which could result in a shortfall in highway diesel fuel supply. Arguably, the refiners which are most likely to exit the highway diesel market would be those which are facing the highest cost to desulfurize their highway diesel fuel. Those most likely to maintain highway production, or even expand production to fill market demand would be the lowest cost producers. In some cases a portion of the market demand for 15 ppm sulfur highway diesel fuel could be met by today's predominant or exclusive producers of nonhighway diesel fuel. To understand ths possibility, we assessed the cost to offhighway diesel fuel producers of desulfurizing their offhighway diesel fuel to make up a potential supply shortfall in highway diesel fuel. In fact, current highway diesel fuel producers which decide they must install a grassroots unit to meet the 15 ppm cap standard would have no advantage over current nonhighway producers producing a similar volume of fuel and processing a similar type of crude oil. The cost analysis allowing for such production shifts between diesel fuel markets by refineries is presented as a sensitivity analysis further below.

Finally, the cost of desulfurizing diesel fuel to meet the 15 ppm cap standard was estimated by several other entities. Mathpro provided estimates for the Engine Manufacturers Association. The National Petroleum Council used the Mathpro estimates and adjusted them based on some concerns which they had on costs. The American Petroleum Institute funded a study by Charles River and Baker and O'Brien to study this issue. Finally, the Department of Energy hired Ensys to estimate the cost of meeting the 15 ppm cap standard. These various cost studies are summarized at the end of this section and the cost estimates are compared to our costs if an appropriate comparison can be made.

The analyses and discussion associated with these issues is contained in the following sections.

b. Derivation of the Fraction of LCO and other Cracked Blendstocks in Highway Diesel Fuel for Each Refinery

In Chapter IV, we established that an important challenge for refiners in meeting the proposed 15 ppm sulfur cap was the LCO fraction of their highway diesel fuel pool. Thus, the first step in segregating refineries according to the difficulty of desulfurization is to estimate each refinery's LCO fraction of their highway diesel fuel pool. This data is generally not publically available, so we estimated these fractions from other sources of information.

First, estimates of the volumes of high and low sulfur distillate produced in the last half of 1998 and the first half of 1999 by each U.S. refinery were obtained from the Energy Information Administration (EIA). According to EIA, U.S. refiners produce a total of 49 billion gallons of distillate per year, with 32 billion gallons (about 65 percent) of that being low sulfur diesel fuel. We determined that highway diesel fuel is produced by 121[h] different refineries throughout the U.S.

Second, we estimated the volume of LCO produced by each refinery using information from the Oil and Gas Journal (OGJ).[34] The OGJ publishes information on the capacity of major processing units for each refinery in the country, including the FCC unit. We assumed that FCC units operate at 90 percent of capacity, which is consistent with the API/NPRA survey of Refining Operations and Product Quality.[35] We first assumed that 17 percent of the feedstock volume to the FCC unit is converted into LCO based on confidential information shared with EPA by a vendor of fluidized cat cracker units. Next we assumed that refineries with distillate hydrocrackers send their LCO to the distillate hydrocracker and convert it to gasoline.

Furthermore, FCC feed hydrotreaters can affect the sulfur level and the treatability of light cycle oil. FCC feed hydrotreaters hydrotreat the gasoil fed to the FCC unit, usually at a pressure much higher than distillate hydrotreaters. The resulting cracked blendstock from the FCC unit is much lower in sulfur, and, most important, some of the sterically hindered compounds are desulfurized. However, only high pressure feed hydrotreaters (i.e., 1500 psi units) can convert a significant portion of these sterically hindered compounds.[36] We don't have

[h] There are four refineries in Alaska producing diesel fuel which is exempted from the current 500 ppm sulfur cap standard for highway diesel fuel. Consequently, the diesel fuel they produce is used for both highway and offhighway purposes without regard to the end use. Since only an estimated 5 percent of diesel fuel in Alaska is consumed in highway applications, for our cost analysis we assumed only one would, in the future, produce highway diesel fuel to supply demand. Thus, we also included that one refinery in this analysis of blendstock quality.

any specific information on what fraction of these hydrotreaters are high pressure, however, industry experts estimated that about 20 percent of the FCC feed hydrotreaters are high pressure, with most or all of these being in California. Since we don't know which feed hydrotreaters are high pressure, we conservatively presume that only the California feed hydrotreaters are high pressure. Since most California refineries already have distillate hydrocrackers, the fact that they have high pressure feed FCC hydrotreaters is a moot point and does not affect the fraction of LCO of these refineries. Consequently, we have not made any adjustments in our cost methodology to account for the presence of FCC feed hydrotreaters.

Based on these assumptions, we calculated the fraction of LCO to total distillate production to be about 15 percent. To independently check this estimate, we compared our estimate of the LCO fraction of total distillate production with that reported in the API/NPRA survey. The API/NPRA survey shows that, on average for the U.S. refining industry as a whole, light cycle oil comprises about 21 percent of number two distillate. For highway diesel fuel, the API/NPRA Survey shows the percentage of LCO to the total pool of highway diesel fuel to be 22 percent, and both of these percentages are much higher than our initial estimate. In our distillate production model, if we increase the fraction of FCC feedstock converted to LCO from 17 percent to 25 percent, our model matches the fraction of LCO to distillate shown by the API/NPRA survey for the highway diesel pool. Thus, we used 25 percent for the ratio of LCO product to FCC feed in our refinery model.

Applying these assumptions using the EIA and OGJ information, we calculated the fraction of LCO relative to the total distillate production for each refinery. We then categorized the refineries based on the fraction of their distillate pool which is LCO at 5 or 10 percent intervals from 0 to 60 percent. The distribution of refineries by fraction of LCO is summarized in Table V.C-1.

Table V.C-1. Presence of Light Cycle Oil in the Distillate of U.S. Refineries Producing Highway Diesel Fuel

	Percentage of LCO in the Distillate Pool								
	0%	<10%	<15%	<20%	<25%	<30%	<40%	<50%	<60%
Number of Refineries	49	51	54	59	71	93	113	116	118
Cumulative Percentage of US Highway Diesel Volume	27	29	32	36	47	77	95	98	99

In Table V.C-1, our analysis shows that distillate contains anywhere from no LCO to 60 percent LCO. Our analysis also shows that 49 U.S. refineries which produce about 27 percent of the distillate in the U.S. blend no LCO into this distillate, while the distillate from the remaining 72 refineries averages about about 28 percent LCO by volume. This is important because of the large difference in fractions of LCO in the highway diesel pool for the U.S refining industry. Refineries which blend no LCO into their distillate pool do so because they either do not have an FCC unit, or because they have a distillate hydrocracker which is used to "upgrade" their LCO to gasoline. Refineries with LCO in their distillate have an FCC unit, and they likely do not have a hydrocracker. The refineries in both groups have distillate hydrotreaters for producing onhighway diesel fuel for meeting the current 500 ppm cap standard.

We also estimated the fraction of other cracked stocks, which includes coker, thermally cracked and visbreaker distillate, in each refinery's distillate fuel. We first estimated the volume of these other cracked stocks produced by each refinery using information from the Oil and Gas Journal (OGJ). Similar to how we calculated the fraction of LCO, we assumed that delayed and fluid cokers, visbreakers, and thermal crackers all operate at 90 percent of capacity. Based on a conversation with a refining industry consultant, we assumed that 30 percent of delayed coker and 15 percent of the other units' product is distillate blended into the distillate pool. Unlike LCO, we do not assume that refineries with hydrocrackers send their other cracked stocks to the hydrocracker for conversion to gasoline. While most refineries probably do not send their other cracked stocks to their hydrocracker, it is also likely that some do for at least some of their other cracked stocks, so our assumption is probably somewhat conservative. After analyzing each refinery's other cracked stock distillate production and averaging that production over the entire industry, we estimate that about 8 percent of the entire highway diesel fuel volume is comprised of these other cracked stocks. This value agrees well with the API/NPRA survey.[37]

Table V.C-2. Presence of Other Cracked Blendstocks in the Distillate of U.S. Refineries Producing Highway Diesel Fuel

	Percentage of Other Cracked Stocks in the Distillate Pool							
	0%	**<10%**	**<15%**	**<20%**	**<25%**	**<30%**	**<40%**	**<50%**
Number of Refineries	89	95	103	111	112	118	120	121
Cumulative Percentage of US Highway Diesel Volume	55	67	77	88	89	95	100	100

As depicted in Table V.C-2, our analysis shows that over half of distillate fuel in the U.S, which is produced by 89 refineries, does not contain other cracked stocks from cokers, visbreakers and thermal crackers. Of the refineries which are projected to blend other cracked stocks into their distillate pool, we estimate that, on average, the distillate from these refineries contains approximately 18 percent of other cracked stocks.

Next we set out to determine the cost of desulfurizing highway diesel fuel. We met with Criterion Catalyst/ABB Lummus, UOP, Akzo Nobel and Haldor Topsoe and a number of refiners. One of these vendors provided diesel desulfurization unit operation and capital cost information for different levels of LCO in diesel fuel, which included none, 15 percent, 23 percent and 30 percent, and varying amounts of coker distillate. Another vendor provided significant cost information for 25 percent LCO in diesel fuel, and 10 percent coker distillate. In addition, information from the other two vendors helped to corroborate the operating and cost information obtained from the first two vendors. This information provided by these vendors allowed us to estimate the cost of desulfurizing the different diesel fuel blendstocks.

The information provided by the vendors is based on typical diesel fuels, however, in reality diesel fuel (especially LCO, and to a lesser degree other cracked stocks) varies in desulfurization difficulty based on the amount of sterically hindered compounds present in the fuel, which is determined by the endpoint of diesel fuel, and also by the type of crude oil being refined. The vendors provided cost information based on diesel fuels with T-90 distillation points which varied from 605 °F to 630 °F, which would roughly correspond to distillation endpoints of 655 °F to 680 °F. These endpoints can be interpreted to mean that the diesel fuel would, as explained in Chapter IV above, contain sterically hindered compounds. However, a summertime diesel fuel survey for 1997 shows that the endpoint of highway diesel fuel varies from 600 °F to 700 °F, thus the lighter diesel fuels would contain no sterically hindered compounds, and the heavier diesel fuels would contain more.[38] Our analysis attempts to capture the cost for each refinery to produce highway diesel fuel which meets the 15ppm cap sulfur standard, however, we do not have specific information for how the highway diesel endpoints vary from refinery to refinery, or from season to season.

Similarly, we do not have information on what type of crude oil is being processed by each refinery as the quality of crude oil being processed by a refinery affects the desulfurization difficulty of the various diesel fuel blendstocks. For example, North Slope crude oil from Alaska contains a higher fraction of aromatic compounds than most other crude oils.[39] If the highway diesel fuel produced from Alaskan crude oil has a high endpoint, the highway diesel fuel would be expected to contain more sterically hindered compounds compared to another diesel fuel produced from a lighter crude oil, such as Western Texas Intermediate, with the same endpoint and the same mix of cracked stocks.

As discussed in Chapter IV, refiners which are producing their highway diesel fuel with a higher endpoint and refining heavier, more aromatic crude oils, they are doing so with an economic incentive. The economic incentive is that those heavier, more sour crude oils are 1 to 2 dollars per barrel less expensive than lighter, sweater crude oils. Also, if the heaviest fraction of highway diesel fuel containing the sterically hindered compounds earns at least 10 dollars per barrel (about 25 c/gal) more when it has been upgraded and blended into highway diesel fuel instead of the most likely alternative, which is to be sold in the resid market.[40] In sum, diesel fuel processed by a particular refiner can either be easier or more difficult to treat than what we estimate depending on how their diesel fuel endpoint compares to the average endpoint of the industry, and depending on the crude oil used. For a nationwide analysis, it is appropriate to base our cost analysis for each refinery on what we estimate would be typical or average qualities for each diesel fuel blendstock. Some estimates of individual refinery costs will be high, others will be low, but be representative on average.

c. Technology and Cost Inputs from Vendors

The most significant cost involved in meeting a more stringent diesel sulfur standard would be the cost of constructing and operating the distillate desulfurization unit. For estimating the cost of building and operating these units, we obtained detailed information on the raw material and utility needs, the capital costs and the desulfurization capabilities from licensors of two different desulfurization technologies.[41] [42] [43] Each vendor provided most of the information needed to allow us to cost out a retrofit to an existing desulfurization unit, and also cost out the building of a new desulfurization unit from grass roots. We also met with two other vendors of desulfurization technology, though they did not provide enough information to develop an independent cost estimate.

In addition to the information which we obtained directly from the vendors, we reviewed the vendor submissions made to the National Petroleum Council (NPC) by Akzo Nobel, Criterion, Haldor Topsoe, UOP and IFP.[44] Of the five vendors which provided information to the NPC; we met with all of them except IFP. These vendors provided information for retrofiting existing diesel hydrotreaters and many of them also provided information on the combined operations of the existing hydrotreater and the revamp together. The full set of submissions made to the NPC allowed us to compare all these vendor's information to each other on the same basis. With one exception, these submissions corroborated the costs we had developed earlier. In one case, though, the vendor's information suggested that a significant amount of hydrogen would be consumed to remove the sulfur, which would also cause a significant increase in API gravity (the diesel fuel would be made less dense). However, the other vendors' information indicated that the sulfur can be removed from diesel fuel without dramatic differences in diesel fuel quality, and with only a modest amount of hydrogen consumption. Thus, we based our estimate of hydrogen consumption on the estimates of hydrogen consumption, as reflected by the majority of the vendors. Conversely, API has indicated that they believe that very high hydrotreating pressures (e.g., 1200 psi or more) will be necessary to meet a 15 ppm cap standard, although their contractor for their cost study indicated that pressures under 1000 psi would be adequate. None of the vendors projected that pressures more than 900 psi would be necessary and most of the vendors projected that 650 psi would be sufficient. Likewise, a number of refiners have indicated that pressures well below 1000 psi would be sufficient. Thus, we based our estimate of capital cost on two different vendor submissions which were based on units operating at 650 and 900 psi pressure.

Since refineries already have a distillate hydrotreater in place to desulfurize highway diesel fuel down to under 500 ppm, the vendors concluded that it would only be necessary to retrofit an existing diesel hydrotreating unit with a number of different vessels, such as a reactor, a hydrogen compressor, a recycle scrubber an interstage stripper and other associated process hardware. Despite the fact that each vendor is basing their cost information on retrofits, the two vendors who provided us information on our cost analysis, still differed in individual cost elements due to differences in the capital equipment used, although the overall cost ended up being roughly the same.

The differences in the estimated capital and operating costs between the two vendors is largely due to the differences in technical approaches assumed by each vendor for meeting the proposed diesel sulfur standards. One vendor, which we will call Vendor A,[i] chose to estimate

[i] Vendor A wished to keep its name confidential. For consistency in our tables we are labeling the second vendor, UOP, as Vendor B.

operating and capital costs for a two-stage revamp, which is operated at a higher pressure.[j] Thus, this vendor would recommend the use of a two stage unit right away instead of opting for other subunits at the higher diesel fuel sulfur levels. The other vendor, which we will call Vendor B, chose to estimate the operating and capital costs for a single stage revamp for moderate levels of desulfurization, which included a larger reactor, hydrogen purification, a recycle gas scrubber, and a color reactor to address the implications of increased reactor temperature. Then, to desulfurize diesel fuel to under 10 ppm, Vendor B would recommend a two stage unit, but without hydrogen purification and at lower temperature which negates the need to install a color reactor. While there are substantial hardware differences between the two vendors for desulfurizing diesel down to levels above 10 ppm, the differences between the vendors diminishes with deeper desulfurization as both vendors use a two stage approach. We believe that there are merits of using either approach and that both approaches would be used by different refiners. Thus, we based our rule on the cost of both vendors representing both approaches and we averaged them together. The technical approach generally used by each vendor to achieve reduced diesel fuel sulfur levels is summarized in the following table. The vendors assumed that the existing desulfurization unit in place would provide a number of hydrotreater subunits which would save on both capital and operating costs for a one or two stage revamp compared to whole new grassroots unit. These subunits include heat exchangers, a heater, a reactor filled with catalyst, two or more vessels used for separating hydrogen and any light ends produced by cracking during the desulfurization process, a compressor, and sometimes a scrubber. The desulfurization subunits listed here are discussed in detail in the feasibility section contained in Chapter IV.

[j] Vendor A provided cost inputs for both low pressure and intermediate pressure units to NPC. The diesel desulfurization costs were similar for each, which suggests that one approach does not have a predictable advantage over the other, however, refinery configuration may provide an advantage of one approach over the other for each individual refiner.

Table V.C-3. Technology Projected to be Used to Achieve Various Diesel Fuel Sulfur Levels

Average Diesel Fuel Sulfur Level	*Vendor A*	*Vendor B*
30 ppm	Change to a more active catalyst Install recycle gas scrubber Modify compressor Install a second reactor, high pressure (900 psi) Use existing hot oil separator for interstage stripper	Change to a more active catalyst Install a recycle gas scrubber Purify make-up hydrogen Install a second reactor (650 psi) Increase temperature in the second reactor and install a color reactor
10 ppm	Same as above Use more catalyst Increase the size of the second reactor	Same as above Use more catalyst Increase the size of the second reactor
<10 ppm	Same as above Increase catalyst volume further Use an even larger second reactor Raise temperature in the second reactor	Same as above, Install an interstage stripper, which negates the need to purify hydrogen and increase the reactor bed temperature Increase size of the second reactor Increase catalyst volume

Prior to presenting the vendor inputs which allowed us to estimate the cost of meeting the 15 ppm cap standard, we will first qualify the information in terms of its perceived accuracy of the actual cost of desulfurizing diesel fuel. We received several comments from refiners which assert that the vendor costs are optimistic and need to be adjusted higher to better assess the costs. While the vendors costs may be optimistic, we believe that there are a multitude of reasons why the cost estimates should be optimistic.

First, capital costs can be lower than what the vendors project. Many refiners have used reactors, compressors, and other vessels which can be employed in a new or revamped diesel hydrotreating unit. We do not know to what extent that additional hydrotreating capacity can be met by using used vessels, however, we believe that at least a portion of the capital costs can be offset by used equipment.

There are also operational changes which refiners can make to reduce the difficulty and the cost of desulfurizing highway diesel fuel. Based on the information which we received from vendors and as made apparent in our cost analysis which follows, refiners with LCO in their diesel fuel would need to hydrotreat their highway diesel pool more severely resulting in a higher cost to meet the cap standard. We believe that these refiners could potentially avoid some or much of this higher cost by pursuing two specific options. The first option which we believe these refiners would consider would be to shift LCO to distillate fuels which do not face such stringent sulfur control, such as off-highway diesel fuel and heating oil. When we analyze the refineries which blend LCO into their diesel fuel, we find that a number of them also produce a significant quantity of high sulfur distillate. The lenient sulfur limits which regulate heating oil and off-highway diesel provide ample room for blending in substantial amounts of LCO. Because of the low cetane value inherent with LCO, refiners cannot simply dump a large amount into off-highway diesel since off-highway diesel must meet an ASTM cetane specification. Thus, we believe that refiners could distill its LCO into a light and heavy fraction and only shift the heavy fraction to off-highway diesel fuels. Essentially all of the sterically hindered compounds distill above 630 ^{o}F, so if refiners undercut their LCO to omit these compounds, they would cut out about 30 percent of their LCO. We expect that refiners could shift the same volume of non-LCO distillate from the highway distillate pool to the highway pool to maintain current production volumes of all fuels. In addition to the cetane limit which limits blending of LCO into off-highway diesel, the T-90 maximum established by ASTM limits would limit the amount of LCO, and especially heavy LCO, which can be moved from highway diesel fuel into the high sulfur distillate streams. For those refineries which could trade the heavy portion of LCO with other blendstocks in the high sulfur pool from own refinery or other refineries, we presume that those refiners could make that separations cheaply by using a splitting column for separating the undercut LCO from the uncracked heavy gasoil in the FCC bottoms.

Another option for refineries which are faced with treating LCO in its highway diesel fuel would be to sell off or trade their heavy LCO to refineries with a distillate hydrocracker. This is a viable option only for those refineries which are located close to another refinery with a distillate hydrocracker. The refinery with the distillate hydrocracker would upgrade the purchased LCO into gasoline or high quality diesel fuel. To allow this option, there must be a way to transfer the heavy LCO from the refinery with the unwanted LCO to the refinery with the hydrocracker, such as a pipeline or some form of water transport. We asked a refinery consultant to review this option. The refinery consultant corroborated the idea, but commented that trading the of blendstocks between refineries is a complicated business matter which is not practiced much outside the Gulf Coast, and that the refineries with hydrocrackers that would buy up and process this low quality LCO may have to modify their distillate hydrocrackers.[45] The modification which may be needed would be due to the more exothermic reaction temperature of treating LCO which could require refiners to install additional quenching in those hydrocrackers. Additionally, LCO can demand 60 to 80 percent more hydrogen for processing than straight run material. The refineries which can take advantage of selling or trading their LCO to these other refineries are mostly located in the Gulf Coast where a significant number of refineries have hydrocrackers and such trading of blendstocks is commonplace. However, we also identified other refineries outside the Gulf Coast which could take advantage of their very close location to another refinery with a distillate hydrocracker. Through a quick analysis, we identified that these refineries which could sell off or trade their heavy LCO to other refineries with hydrocrackers produce about 25 percent of the highway diesel fuel in this country.

As we summarized in Chapter IV, catalysts are improving and expected to continue to improve. Our costs are based on vendor submissions and incorporate the most recent catalysts which they have to offer, however, as catalysts continue to improve, the cost of desulfurizing diesel fuel will continue to decrease.

Emerging technologies provide another opportunity for the cost of desulfurizing diesel fuel to be much lower than what we have estimated. Enchira Biosystems Corp., which was Energy BioSystems Corp., created and has been developing a process which uses genetically enhanced bacteria for oxidizing the sulfur molecules in diesel fuel, and then extracts the oxidized sulfur-containing petroleum molecules to sell as a surfactant on the chemicals market.[46] Another similar process has been created by Petrostar. The Petrostar process also oxidizes the sulfur molecules in diesel fuel, but uses an oxidation compound to do so.[47] Finally, Phillips has adapted their gasoline desulfurization process, which relies on adsorption, to diesel fuel. These various processes are still being developed, though, and may not be ready in time for making the implementation date of this final rule.

In summary, if the vendor cost estimates are optimistically low, there are a number of reasons why the cost of desulfurizing highway diesel fuel to meet the 15 ppm cap standard are likely to be low. Vendors are expected to continue to improve their desulfurization technology such as the activity of their catalysts. Also, refiners have several cost cutting options at their disposal such as using existing spare equipment to lower their capital costs. Also, refiners may be able to resort to either of two operational options to reduce the amount of LCO in their highway diesel fuel. Furthermore, refiners could choose to use emerging technology which could offer significant reductions in the cost of desulfurizing diesel fuel.

We next present diesel fuel desulfurization information provided by the vendors for typical diesel fuel blends containing 8 percent and 10 percent coker, 23 percent and 25 percent LCO and the balance straight run, and another containing only straight run. This information is summarized below in Tables V.C-4 & 5. This information was provided either for a revamp or for a grassroots unit, which is indicated.

Table V.C-4. Process Projections to Desulfurize a Typical Diesel Fuel[A] (Information Provided for a Retrofit Unless Indicated)

	Vendor A 50 ppm 900 psi Hydrotreat.	***Vendor A 10 ppm 900 psi Hydrotreat.***	***Vendor A 7 ppm 900 psi Hydrotreat.***	***Vendor B 30 ppm 650 psi Hydrotreat.***	***Vendor B 10 ppm 650 psi Hydrotreat.***	***Vendor B 7 ppm 650 psi Hydrotreat.***
Capacity (bbl/stream day)	25,000	25,000	25,000	31,200	31,200	31,200
Capital Cost (ISBL) (MM$)	15 - 18	15 - 18	1 more than at 10 ppm	5.5	7	15
LHSV (Liquid Hour Space Velocity (Hr^{-1})	2.5 1.25*	1.5 1.0*	0.8[B]	1.5	0.9	NP
Chemical Hydrogen Consumption (SCF/bbl)	100 325[B]	160 375[B]	20 more than at 10 ppm	70 330[B]	115 375[B]	NP
Electricity (KwH/bbl)	0.30	0.36	NP	0.5	0.6	NP
HP Steam (Lb/bbl)	-	-	-	-	-	-
Fuel Gas (BTU/bbl)	-2.2[C]	-2.9	NP	100	100	NP
Catalyst Cost ($/bbl)	0.06	0.08	NP	0.14	0.41	NP
Yield Loss (wt%) Diesel	1.42[B]	1.51[B]	NP	NP	NP	NP
Naphtha	-0.89[B]	-1.06[B]	NP	NP	NP	NP
LPG	-0.05[B]	-0.06[B]	NP	NP	NP	NP
Fuel Gas	-0.09[B]	-0.10[B]	NP	NP	NP	NP

[A] This diesel fuel contains 23% LCO, 8% coker, and 69% straight run for Vendor A, and 25% LCO, 10% coker and 65% straight run for Vendor B.
Sulfur levels in the table are averages.
NP = not provided.
[B] Information provided for a grassroots unit.
[C] Information provided for achieving 30 ppm; negative values indicate exothermic reactions.

Table V.C-5. Process Projections to Desulfurize 100% Straight Run Diesel Fuel (Information is for a Grassroots Unit)

	Vendor A *50 ppm* *800 psi Hydrotreating*	*Vendor A* *10 ppm* *800 psi Hydrotreating*
Capacity BPSD (bbl/day)	25,000	25,000
Capital Cost (ISBL) (MM$)	NP	NP
LHSV (Liquid Hour Space Velocity (Hr^{-1})	1.6	1.25
Hydrogen Consumption (SCF/bbl)	210	225
Electricity (KwH/bbl)	NP	NP
HP Steam (Lb/bbl)	-	-
Fuel Gas (BTU/bbl)	NP	NP
Catalyst Cost ($/BPSD)	34	45
Yield Loss (wt%) Diesel Naphtha LPG Fuel Gas	NP	NP

NP = not provided.
Sulfur levels in the table are averages.

We are aware that there are potentially other capital and operating costs in the refinery which would contribute the projected cost of desulfurizing diesel fuel beyond that provided to us by the vendors. For example, refiners may need to expand their amine plant or their sulfur plant to enable the processing of the sulfur compounds removed from diesel fuel. Then the small amount of additional sulfur compounds treated would incur additional operating costs. Thus, we adjusted the projected capital and operating costs upward to account for these other potential costs which we have not accounted for directly. Our contingency factors, described further below, are 1.18 for capital and 1.12 for operating costs.

d. Development of Diesel Desulfurization Cost Projections

After obtaining the information from Vendors A and B, and corroborating their submissions based on some other information which we obtained from other vendors, we needed to apply this information to estimate the cost of meeting the 15 ppm highway diesel fuel cost standard. However, in many cases the information provided by the vendors was not sufficient for inserting directly into our cost model. Vendors A and B provided most of the information needed to cost out both a revamp and a grassroots unit. However, for some of the cost inputs for our refinery model, the information provided by the vendors is for a grassroots unit and it must be adjusted to reflect the impact or cost of a revamp, and vice versa. In other cases, no information was presented at all so we developed a method for estimating the necessary cost inputs.

In the case where we only received information for a grassroots unit for a specific cost, we typically estimated the cost of a revamp using ratios of the liquid hour space velocity (LHSV) provided by the vendor for a revamp. Using LHSV seems reasonable considering that the value is inversely proportional to the catalyst and reactor volume projected to be necessary to accomplish the required desulfurization. Thus, applying the inverse of LHSV for meeting differing sulfur levels should be a good surrogate for the ratio of costs. We did not receive information from Vendor B for desulfurizing 100% straight run diesel fuel, but instead of relying only on the information from Vendor A, we projected Vendor B's costs using the percentage difference in costs estimated by Vendor A for treating a 100% straight run feed compared to a typical feed. Using information from both vendors for estimating the cost for the sensitivity analysis results in a better comparison with the case which assumed a typical mix of diesel blendstocks. For meeting the 15 ppm cap standard, which we estimate to mean achieving 7 ppm on average, the vendors did not provide specific cost information for many of the individual cost elements, thus we extrapolated the costs. While hydrogen consumption and space velocity information was provided by Vendor A specifically, the other cost elements, such as catalyst cost, yield loss and utility costs were projected using the ratio of the LHSV or by extrapolating the costs from the higher sulfur levels. These extrapolations are described in detail below Tables V.C-6 and V.C-7.

Cost Projections for a Typical Feed

The adjusted vendor capital and operating cost information is summarized in Tables V.C-6. and V.C-7. below.

Table V.C-6. Process Projections for Revamping an Existing Highway Diesel Hydrotreater for Further Desulfurizing a Typical Diesel Fuel[A]

	900 psi (Based on Vendor A)			*650 psi (Based on Vendor B)*		
Average Sulfur Level	*50 ppm*	*10 ppm*	*7 ppm*	*30 ppm*	*10 ppm*	*7 ppm*
Capacity (bbl/stream day)	25,000	25,000	25,000	31,200	31,200	31,200
Capital Cost (ISBL) (MM$)	16	18	19	5.5	7	15
LHSV (Liquid Hour Space Velocity (Hr^{-1})	2.5	1.5	1.2	1.5	0.9	0.7
Hydrogen Consumption (SCF/bbl)	125	185	205	95	154	160
Electricity (KwH/bbl)	0.24	0.36	0.37	0.5	0.6	0.6
Fuel Gas (BTU/bbl)	-1.5	-2.9	-3.0	100	100	100
Catalyst Cost ($/bbl)	0.06	0.08	0.1	0.14	0.41	0.51
Yield Loss (%)						
Diesel	0.8	1.0	1.3	0.9	1.0	1.3
Naphtha	-0.5	-0.71	-0.88	-0.54	-0.71	-0.88
LPG	-0.03	-0.04	-0.05	-0.03	-0.04	-0.05
Fuel Gas	-0.05	-0.07	-0.08	-0.05	-0.07	-0.08

[A] This typical diesel fuel contains 23% LCO, 8% coker, and 69% straight run for Vendor A, and 25% LCO, 10% coker and 65% straight run for Vendor B.

When available, the information contained in Table V.D-6. reflects exactly the information provided by the two vendors. However, the vendors did not provide projections for some of the relevant factors. These factors were estimated from the information provided by the other vendor or otherwise, as described below.

As stated above under Table V.C-4., Vendor A provided a range of $15 - $18 million for the capital costs of desulfurizing diesel fuel from the base to 50 ppm and from the base down to 10 ppm. Consistent with the methodology laid out above, we assigned the capital cost of desulfurizing diesel fuel with 23 percent LCO down to 50 ppm as $16 million, and the cost of producing 10 ppm diesel as $18 million. For achieving a sulfur level of 5 ppm, Vendor A estimated the additional capital cost to be $1 million more, which we used for our estimated 7 ppm case. For Vendor B, we have two sources of information for the capital costs which seem to vary at the 10 ppm level. We based the cost analysis on the explicit cost provided by Vendor B. However, interpolating the capital cost from Vendor B's second information source suggests that the capital cost for desulfurizing diesel fuel to the 10 ppm level may be fifty percent higher.

We are aware that small leaks in the heat exchangers of existing highway diesel hydrotreating unit can lead to contamination of the product stream. Even a small leak of tenths of a percent in volume of high sulfur feed into the very low sulfur product could ruin batches of the product. For this reason, many refiners who chose to revamp their existing diesel hydrotreaters are expected to take preventative measures against contamination by welding the heat exchanger tubes to the plates, or by replacing their heat exchangers altogether.[48] To account for this added cost we assumed that each refinery would invest a million dollars to revamp or, in some cases, completely replace their highway diesel heat exchangers to ensure that they could meet a 15 ppm diesel fuel sulfur standard.[49]

Since neither Vendor A nor Vendor B provided estimates of the LHSV for a retrofit unit down to 5 ppm, we calculated Vendor A's ratio of the LHSV for achieving 5 ppm to the LHSV for achieving 10 ppm for a grassroot unit, and applied the ratio to the LHSV values for retrofits for both Vendor A and Vendor B for 10 ppm.

Vendor A estimated hydrogen consumption for achieving 5 ppm as 25 SCF/bbl higher than that for achieving 10 ppm. To desulfurize down to 7 ppm from 10 ppm, we assume that an additional 20 scf/bbl would be necessary. Since Vendor B did not provide a estimate for achieving 7 ppm, we applied Vendor A's increased hydrogen consumption to Vendor B. At all levels of desulfurization, we assume that each characteristic refinery would lose 25 standard cubic feet per barrel (SCF/bbl) hydrogen due to solution and purge losses for the revamp.[50] [51] Solution losses of hydrogen is the hydrogen which becomes entrained in the highway diesel fuel and thus is no longer available to recycle back to the diesel hydrotreater. Purge losses is the intentional bleeding off of the hydrogen stream and sending that stream to plant gas to prevent a high concentration of nonreactive gases, such as methane, from being recycled back to the reactors.

The electricity necessary for achieving 7 ppm sulfur is extrapolated from the 10 ppm and 50 ppm cases for both Vendor A and Vendor B.

The catalyst cost for achieving 7 ppm for a revamp for Vendor A and Vendor B is estimated by multiplying Vendor A's ratio of the LHSV for 10 ppm divided by the LHSV for 7 ppm for a grassroots unit times the LHSV for 10 ppm for a revamp.

The yield loss and resulting by products produced which was provided by Vendor A for a grassroots unit was adjusted to project the yield loss for a revamped unit using the ratio of the LHSV of a grassroots unit to the LHSV of a retrofitted unit. Since Vendor B did not provide yield loss information, Vendor A's yield loss and by-product information was applied to Vendor B. This seems reasonable because the LHSV (which indicates the contact time which diesel has with the catalyst) for both vendors is similar and yield loss would likely be proportional to the contact time of diesel fuel with the catalyst.

Cost Projections for a Straight Run Feed

Table V.C-7. Process Projections for Revamping an Existing Highway Diesel Hydrotreater for Desulfurizing 100% Straight Run Diesel Fuel

	800 psi (Based on Vendor A)			***650 psi (Based on Vendor B but adjusted using Vendor A's information)***		
	50 ppm	*10 ppm*	*7 ppm*	*30 ppm*	*10 ppm*	*7 ppm*
Capacity (bbl/stream day)	25,000	25,000	25,000	31,200	31,200	31,200
Capital Cost (ISBL) (MM$)	15	17	18	5.5	6.2	11
LHSV Liquid Hour Space Velocity (Hr^{--1})	2.8	1.9	1.5	1.7	1.1	0.9
Hydrogen Consumption (SCF/bbl)	95	100	107	80	84	90
Electricity (KwH/bbl)	0.28	0.35	0.35	0.5	0.6	0.6
Fuel Gas (BTU/bbl)	-1.5	-2.9	-3.0	100	100	100
Catalyst Cost ($/bbl)	0.03	0.05	0.07	0.11	0.33	0.41
Yield Loss (wt%) Diesel Naphtha LPG Fuel Gas	0.6 -0.4 -0.02 -0.04	0.8 -0.6 -0.03 -0.05	1.0 -0.7 -0.04 -0.07	0.7 -0.4 -0.03 -0.04	0.8 -0.6 -0.03 -0.05	1.0 -0.7 -0.04 -0.07

When available, the information contained in Table V.C-7. reflects exactly the information provided by the two vendors. However, the vendors did not provide projections for some of the relevant factors. These factors were estimated from the information provided by the other vendor or otherwise, as described below.

Vendor A did not provide a specific capital cost for a 100 percent straight run diesel case. Instead, the vendor estimated a capital cost of $15-18 million for a refinery processing different amounts of LCO to meet a range of final sulfur levels of 10-50 ppm. Based on discussions with the vendors, we surmised that increased amounts of LCO provides a similar extent of difficulty for desulfurization as decreasing the sulfur level in this range of desulfurization. Thus, we estimated the capital cost for the 100 percent straight run case for 50 ppm sulfur to be at the lowest end of the range ($15 million) and to be $16 million for 10 ppm, since diesel fuel without LCO is easier to desulfurize than diesel containing LCO. Also, the increment of $1 million was the cost estimated by this vendor of reducing sulfur from 10 ppm to 5-10 ppm for LCO containing material, so we used the same increment for this case as well. In Table V.C-6. above, the capital cost for treating a typical diesel fuel falls within the upper part of Vendor A's capital cost range.

Vendor B also did not provide capital costs for a no LCO case. Since we had no information from Vendor B for how it would allocate its capital costs for varying levels of LCO, we assumed that the capital costs for the no LCO cases producing sulfur at 10 ppm or higher would be the same as those for the 23 percent LCO case. While this assumption may be conservative, we felt comfortable with this assumption because of the low capital costs projected by Vendor B. However, below 10 ppm, instead of the large increase in capital cost projected for the 23 percent LCO case, we projected that the capital cost would be halfway between the increase for the 23 percent case, which would be $11 million. This assumption seemed reasonable since straight run contains some sterically hindered compounds which requires more reactor volume to treat, although still much less than that of the 23 percent LCO case.

The hydrogen consumption for this retrofit case was calculated using the ratios of the retrofit case for the case with 23 percent LCO. Vendor B's hydrogen consumption for a grassroots case with no LCO was estimated first assuming the same hydrogen consumption as Vendor A, however, the retrofit hydrogen consumption for Vendor B is a smaller ratio than that of Vendor A.

The LHSV for both vendors' retrofit technology for the no LCO case was estimated from the information which they provided for the grassroots units. The ratio of the LHSV for the grassroots units treating no LCO to the LHSV for the grassroots unit treating 23 percent LCO was applied to the LHSV for the retrofit unit treating 23 percent LCO to project the LHSV for the retrofit unit treating no LCO.

Electricity consumption for the no LCO cases was assumed to be 97 percent of that for the 23 percent LCO cases based on the ratio of specific gravities for the two different feeds, since the density of the fuel governs the pumping energy consumed for moving the fuel. Fuel gas consumption for treating the non-LCO feed was assumed to be the same as that for the 23 percent LCO case. The catalyst cost for the non-LCO feed was assumed to be proportional to the ratio of the LHSV of the no LCO and 23 percent LCO cases. The yield loss of the no LCO case was adjusted downward from the 23 percent LCO case using ratios of the LHSV; since Vender B did not provide yield loss information, Vendor A's information was applied to Vendor B's technology as well.

e. Development of Desulfurization Cost Factors for Individual Diesel Blendstocks

Once we established the inputs for estimating the cost of desulfurizing a typical diesel fuel containing both straight run and cracked stocks, we set out to estimate the inputs for each individual blendstock. Configuring our cost analysis to estimate costs based on the estimated highway diesel blend of each refinery gave us more confidence in our cost analysis. We already had the inputs for straight run from a submission from Vendor A. Next we needed to estimate the inputs for light cycle oil and for the other cracked stocks. We used some of the information we obtained from our discussions with the vendors to make these estimates. Since we need to estimate costs for both a revamp and a grassroots units for each refinery, it was necessary to develop costs for both. These costs are presented in Table V.C-8 for a revamped unit, and further below in Table V.C-9 for a grassroots unit. The methodology for developing those costs are described below each Table.

Individual Blendstock Process Projections for a Revamp

These process projections are for revamping an existing desulfurization unit with additional hardware enabling the combined older and new unit to meet the 15 ppm sulfur cap standard. If a refiner decides to replace their existing highway diesel fuel desulfurization unit with a new grassroots unit, we assume that the operating costs of the new unit would still be the same as a revamped unit because the refiner has already been incurring the operating cost for producing 350 ppm highway diesel fuel. We assume the refiner would, however, incur all the capital cost of the new unit.

Table V.C-8. Process Projections for Revamping an Existing Highway Diesel Hydrotreater for Further Desulfurizing Diesel Fuel Blendstocks to Meet a 15 ppm Cap Standard

	Straight Run	*Other Cracked Stocks*	*Light Cycle Oil*
Capacity BPSD (bbl/day)	25,000	25,000	25,000
Capital Cost (ISBL) (MM$)	16	19	22
LHSV (Liquid Hour Space Velocity (Hr^{-1})	1.25	0.7	0.6
Hydrogen Consumption (SCF/bbl)	96	230	375
Electricity (KwH/bbl)	0.4	0.7	0.8
HP Steam (Lb/bbl)	-	-	-
Fuel Gas (BTU/bbl)	40	70	80
Catalyst Cost ($/BPSD)	0.2	0.4	0.5
Yield Loss (wt%) Diesel	1.0	1.9	2.2
Naphtha	-0.7	-1.3	-1.5
LPG	-0.04	-0.07	-0.08
Fuel Gas	-0.04	-0.11	-0.13

The information in Table V.C-8 was derived from the Tables V.C-4-7 above, from Table V.C-9 below, and using other inputs and assumptions as described below.

Capital Costs

The inside battery limits (ISBL) capital costs for revamping a hydrotreater to handle straight run was estimated by averaging the values for Vendors A and B from Table V.D-7. A $1 million sum was added to that sum to account for improvements to existing heat exchangers such as welding the tubes to the tubesheets, and for some refiners to replace their heat exchangers altogether.

The ISBL capital cost of treating coker and other cracked stocks is based on the need to have more catalyst and reactor volume and probably a higher pressure than straight run to treat a greater volume of sterically hindered compounds. The difficulty in treating coker distillate was presumed to be similar to treating 1/3 LCO, 1/3 coker distillate and 1/3 straight run, because the volume of sterically hindered compounds is similar to that combination of blendstocks. This is a useful comparison to make because in their submission to us, Vendor A provided a capital cost estimate for treating such a mix down to 10 ppm. Vendor A presumed that refiners would need to invest $19 million, which is at the high end of the range given by Vendor A for achieving 10 ppm for a range of feeds, of which this particular blend of diesel stocks was the worst. This value was increased by $1 million to achieve 7 ppm and another $1 million to revamp or replace the heat exchangers, which increased the sum to $21 million. Like the case with 23 percent LCO in the diesel fuel, Vendor B’s capital costs were presumed to be $4 million less than Vendor A’s capital costs, which would still include the $1 million for improvements to existing heat exchangers. On average, treating coker distillate is estimated to cost $19 in capital costs.

The ISBL capital cost for a revamp to an existing diesel hydrotreater for treating LCO can be estimated from some assumptions on the relative difficulty of treating the sterically hindered compounds contained in LCO. LCO contains proportionally more sterically hindered compounds than what the other cracked stocks are estimated to contain relative to straight run (coker distillate contains slightly more than twice the percentage of sterically hindered compounds as straight run, and LCO contains a little more than twice the percentage of sterically hindered compounds as the other cracked streams).[52] Based on this observation and assuming that the increased reactor volume and higher pressure needed to treat LCO is proportionally higher than treating other cracked stocks compared to straight run distillate, we presume that the capital costs are proportionally higher as well. Thus, the capital cost was increased by the same amount over the other cracked stocks as the difference between the other cracked stocks and straight run, which is $3 million more. Then the same $1 million increase was assumed for improving the heat exchangers. Thus, hydrotreating LCO is estimated to cost $22 million in capital costs.

Hydrogen Consumption

The hydrogen consumption for treating straight run, other cracked stocks and LCO was calculated from the values in Table V.C-8 for desulfurizing these untreated distillate streams in a grassroots hydrotreating unit down to 7 ppm. Based on the relative hydrogen consumption for revamped units versus grassroots units from Vendor A and B for a typical feed, the revamped hydrogen consumption is estimated to be about one-third of the hydrogen consumption of the grassroots unit for straight run and LCO. However, because of the high olefin content of the other cracked stocks which consumes a significant amount of hydrogen in a first stage, a revamp would only be expected to require one-fourth of the estimated amount of hydrogen consumed in a grassroots unit. These factors are applied to the hydrogen consumption values without losses, and the losses are added back after multiplication by the various factors. For treating straight run and other cracked stocks, the losses for a grassroots unit are small and assumed to not be lower for a revamped unit. However, the larger losses for treating LCO are assumed to decrease to 25 scf/bbl from the 50 scf/bbl assumed for the grassroots unit. Based on these factors, hydrogen consumption, including losses, for a revamped highway diesel fuel desulfurization unit for meeting the 15 ppm cap standard is 96 scf/bbl for straight run, 230 scf/bbl for other cracked stocks, and 375 scf/bbl for LCO

Space Velocity and Other Operating Costs

The estimated space velocity for a revamped unit treating straight run, other cracked stocks and LCO was calculated from the space velocity values for a grassroots unit summarized below. According to Vendor A, who estimated the space velocity for both a grassroots unit and a revamp for desulfurizing an average blend of diesel fuel down to an average of 10 ppm, a revamped unit's space velocity is 50 percent higher than a grassroots unit. This factor was applied to the space velocities for a grassroots unit listed in Table V.C-8.

The utilities, the catalyst cost and the yield loss were costed out using the space velocity as the cost factor. This calculation was implemented by using the reciprocal of the space velocity, which is the residence time, and multiplying it times each of these operating cost inputs. The catalyst volume would correlate exactly with this relationship, and a less than perfect, but reasonable, correlation would be expected with yield loss and utility cost. The loss of diesel mass was estimated with this approach, however, the cost was ultimately calculated outside of these equations as described below.

Individual Blendstock Process Projections for a Grassroots Unit

Similar process projections are provided for a grassroots unit in this section. It is important to note that a refinery only producing, or predominantly producing, non-highway diesel fuel would be faced with these estimated costs. However, as stated above, if a refinery has an existing hydrotreater for desulfurizing their highway diesel fuel and they install a grassroots unit instead of revamping their existing hydrotreater, they would incur the capital costs outlined here, but their operating costs would be based on a revamp as described above.

Table V.C-9. Process Projections for Installing a New Grassroots Unit for Desulfurizing Untreated Diesel Fuel Blendstocks to Meet a 15 ppm Cap Standard

	Straight Run	***Coker Distillate***	***Light Cycle Oil***
Capacity BPSD (bbl/day)	25,000	25,000	25,000
Capital Cost (ISBL) (MM$)	31	37	42
LHSV (Liquid Hour Space Velocity (Hr^{-1})	0.8	0.5	0.4
Hydrogen Consumption (SCF/bbl)	240	850	1100
Electricity (KwH/bbl)	0.6	1.1	1.2
HP Steam (Lb/bbl)	-	-	-
Fuel Gas (BTU/bbl)	60	105	120
Catalyst Cost ($/BPSD)	0.3	0.6	0.8
Yield Loss (%) Diesel	1.5	2.9	3.3
Naphtha	1.1	2.0	2.3
LPG	0.06	0.11	0.12
Fuel Gas	0.06	0.17	0.20

The information in Table V.C-9 was derived from Tables V.C-4 through Table V.C-7 above for desulfurizing highway diesel fuel down to 7 ppm, and using other inputs and assumptions as described here.

Capital Costs

The capital costs for a grassroots hydrotreater was calculated simply by increasing the cost of a revamp by a factor two. This same calculation was used for straight run, coker distillate and light cycle oil. The basis for this calculation is that Vendor A's information provided for both a revamp and a grassroots unit for desulfurizing a typical feed to meet a stringent sulfur standard showed that the grassroots unit's ISBL investment cost is projected to cost two times higher than a revamp. The $1 million sum which was added to the revamped case to account for improvements to existing heat exchangers was not included in the grassroots capital cost since the grassroots unit includes new heat exchangers.

Hydrogen Consumption

The hydrogen consumption rate for straight run, coker distillate and light cycle oil were estimated by applying certain factors used by vendors for estimating hydrogen consumption. One such factor is that about 25 standard cubic feet per barrel (scf/bbl) of hydrogen is consumed for each volume percent of polynuclear aromatics saturated to monoaromatics.[53 54] As described in Chapter IV, many of the polynuclear aromatics (PNAs) are saturated to monoaromatics to enable desulfurization of the sterically hindered sulfur compounds. On a molecular level, four hydrogen atoms are consumed for each PNA saturated to a monoaromatic. According to Mathpro, about half the total amount of aromatics in a diesel blend are PNAs: straight run contains about 8 volume percent PNAs, coker distillate contains about 20 volume percent PNAs , and LCO contains about 55 volume percent PNAs.[55] However, these values are typical values within a range of values which can vary depending on the type of crude oil processed by each refinery and operating conditions of the unit producing the individual blendstock. Since we do not know these variables for each refinery producing highway diesel fuel, we used the typical values listed here. In a submission from Vendor A, which was based on feed qualities from Mathpro, 5 volume percent of the PNAs are estimated to be saturated to monoaromatics to achieve an average of 10 ppm sulfur. The conversion of this 5 volume percent represents about two thirds of the total volume of PNAs shown to be typical for straight run by Mathpro. Thus, if a similar fraction of PNAs are saturated for each blendstock, 12 percent of the PNAs in coker (2/3 of 20) and 34 percent of the PNAs in LCO (2/3 of 55) would be converted to monoaromatics. Since we don't have other information on which we can base our estimate of the hydrogen consumption for the saturation of PNAs in LCO and other cracked stocks, we used this factor for estimating this form of hydrogen consumption. As an example of how to apply the factor described above, to estimate the hydrogen consumed due to the saturation of PNAs when desulfurizing straight run down from uncontrolled levels of sulfur to 10 ppm, we would multiply the 25 scf/bbl factor times the 5 volume percent of PNAs saturated, thus, 125 scf/bbl of hydrogen would be consumed.

Of course the sulfur in each of these different blendstocks must be hydrotreated out of the sulfur-containing hydrocarbon compounds. For most of the sulfur, four hydrogen atoms are consumed to remove each sulfur atom. According to Vendor B, removing sulfur from diesel fuel consumes 125 scf/bbl for each weight percent of sulfur removed.[56] According to Mathpro, typical straight run, LCO, and coker distillate contain on the order of 0.7, 1.3 and 3 percent sulfur, respectively. As an example, removing the sulfur from a typical straight run feedstock would consume 85 scf/bbl of hydrogen (0.7 multiplied times 125 scf/bbl) to desulfurize each barrel of untreated straight run diesel fuel down to 10 ppm suflur.

During the hydrotreating process, the hydrocarbons which are olefins are very readily and completely saturated to paraffins which consumes two additonal atoms of hydrogen for each olefin. Coker distillate, and to a lesser degree, LCO contain some olefins which are readily saturated at the top of any hydrotreater. One vendor we spoke to estimated that coker distillate contain 30 volume percent olefins, which consumes on the order of 6 scf/bbl of hydrogen per each volume percent of olefins saturated.[57] We do not have an estimate for the olefin content of LCO, however, we believe that LCO does contain some so we presume that it is about one-fifth as much as coker distillate, or about 6 volume percent. As an example, saturating the olefins in coker would consume 180 scf/bbl of hydrogen (30 times 6 scf/bbl) per each barrel of coker distillate hydrotreated

Since the level of conversion of polyaromatics to monoaromatics was consistent with achieving 10 ppm sulfur, this value must be increased to be consistent with achieving 7 ppm sulfur. According to Vendor A, about another 20 scf/bbl are consumed to make up the difference between 7 ppm and 10 ppm for a typical feed which, as described above, is comprised of 69 percent straight run, 8 percent coker and 23 percent LCO. Allocating this increased hydrogen consumption to each blendstock we estimate that straight run will consume 8 scf/bbl more hydrogen, other cracked stocks would consume about 15 scf/bbl more hydrogen and LCO would consume about 50 scf/bbl more hydrogen. This allocation is based on the relative concentrations of PNAs contained in each of these blendstocks.

The estimated amount of hydrogen consumption for each blendstock is summarized in the following table.

Table V.C-10. Estimated Hydrogen Consumption to Desulfurize Nontreated Distillate, Stocks to Meet the 15 ppm Highway Diesel Fuel Sulfur Cap

	Conversion of Polynuclear Aromatics to Monoaromatics	***Sulfur Removal***	***Saturation of Olefins***	***Total Hydrogen Consumption***
Straight Run	133	85	0	223
Other Cracked Stocks	325	375	180	875
LCO	900	165	35	1100

After deriving these hydrogen consumption estimates for each blendstock, we compared these estimates to the estimated amount of hydrogen consumed by Vendors A and B for desulfurizing three different feeds down to 10 ppm. Vendor A provided hydrogen consumption estimates for straight run, a blend of 69 percent straight run, 8 percent coker and 23 percent LCO, and a blend of 1/3 straight run, 1/3 coker, and 1/3 LCO (not summarized above, but was submitted to the docket). Vendor B provided hydrogen consumption estimates for a blend of 65 percent straight run, 10 percent coker and 25 percent LCO. This comparison is summarized in Table V.C-11 below.

As shown in Table V.C-11, our estimated hydrogen consumption values seem to agree fairly well with those provided by the vendors. The straight run and 1/3-1/3-1/3 feedstock are both quite close. However, the estimated hydrogen consumption for a typical feed, which is either 69 or 65 percent SR, 8 or 10 percent coker, and 23 or 25 percent LCO is between 20 to 30 percent high, with the highest discrepancy with Vendor B's estimated hydrogen demand. This 69 or 65 percent SR feed is probably the most important since it really represents the average of diesel fuel today. The 1/3 SR, 1/3 other cracked and 1/3 LCO, stock feed is heavier than average diesel fuel today. Because we are only modelling the average endpoint, we would be expected to estimate a lower hydrogen consumption value compared to heavier feeds. For these reasons, we recalculated the hydrogen consumption adjusting it downward by 5 percent. These recalculated values are summarized in the last column in Table V.C-11. This recalculation reduces the estimated hydrogen consumption values of straight run from 223 to 213 scf/bbl, other cracked stocks from 875 to 830 scf/bbl, and LCO from 1100 to 1045 scf/bbl.

Table V.C-11. Comparison of Calculated Hydrogen Consumption with the Hydrogen Consumption provided by Vendors A and B for Specific Distillate Feeds

	Vendor A	***Vendor B***	***Calculated Hydrogen Consumption***	***Recalculated Hydrogen Consumption***
Straight Run	233		223	212
69 % straight run, 8 % coker, 23% LCO	395		476	450
65 % SR, 8% coker, 23% LCO		395	507	480
1/3 straight run, 1/3 coker, and 1/3 LCO	730		732	695

The hydrogen consumption values summarized in Table V.C-11 are only meant to represent the chemical consumption of the hydrogen consumption, which is the hydrogen which reacts with the hydrocarbon. Additional hydrogen is lost through entrainment in the diesel fuel and other losses. When hydrogen becomes entrained in the diesel fuel and it is not recovered for reuse, it is called solution losses. Other losses can occur through leaks from the unit or perhaps due to flaring in cases of unit overpressure or due to a constant purge to prevent accumulation of inerts in the hydrogen stream. To account for these losses, we added 25 scf/bbl for straight run and the other cracked stocks, and 50 scf/bbl for LCO. Accounting for hydrogen losses, our hydrogen consumption values increase to about 240 scf/bbl for straight run, 850 scf/bbl for other cracked stocks, and 1100 scf/bbl for LCO.

Space Velocity and Other Operating Costs

The space velocity for a grassroots hydrotreater was calculated by multiplying the space velocity of a revamp by a factor of 0.66 (a fifty percent increase in residence time). This same adjustment was used for straight run, coker distillate and light cycle oil. The information provided by Vendor A was the basis for using this adjustment factor as the space velocity for a grassroots diesel hydrotreater treating a typical blend of straight run, coker distillate and light cycle oil was two thirds the space velocity of a revamp. In terms of residence time, a grassroots unit requires about 50 percent more residence time compared to a unit which is a revamp to an existing diesel hydrotreater.

The utilities, the catalyst cost and the yield loss were costed out using the space velocity as the cost factor. This calculation was made by using the reciprocal of the space velocity, which is the residence time, and multiplying it times each of these operating cost inputs. The catalyst volume correlates exactly with this relationship, and a reasonable correlation would be expected with yield loss and utility cost as well. The loss of diesel mass was estimated with this approach, however, the cost was ultimately calculated outside of these equations as described below.

Hydrocrackate Processing and Tankage Costs

We believe that refineries with hydrocrackers will have to invest some capital and incur some operating costs to ensure that recombination reactions at the exit of the second stage of their hydrocracker does not cause the diesel fuel being produced by their hydrocracker to exceed the cap standard. The hydrocracker is a very severe hydrotreating unit capable of hydrotreating its product from thousands of ppm sulfur to essentially zero ppm sulfur, however, hydrogen sulfide recombination reactions which occur at the end of the cracking stage, and fluctuations in unit operations, such as temperature and catalyst life, can result in the hydrocracker diesel product having up to 30 ppm sulfur in its product stream.[58] [59] Thus, we assume that refiners will need to install a finishing reactor for the diesel stream produced by the hydrocracker. According to vendors, this finishing reactor is a low temperature, low pressure hydrotreater which can desulfurize the simple sulfur compounds which are formed in the cracking stage of the hydrocracker. The finishing reactor adds about 0.25 c/gal to the cost of desulfurizing diesel fuel for those typical refineries with distillate hydrocrackers.

Additionally, since the diesel sulfur standard is a cap standard, we are taking into account tankage costs that would be incurred due to the cap standard. We believe that refiners could store high sulfur batches of highway diesel fuel during a shutdown of the highway diesel hydrotreater. Highway diesel production would cease in the short term, but the rest of the refinery could remain operative. To account for this, we provided for the installation of a tank that would store 10 days of highway diesel production sufficient for a 10 day emergency turnaround which is typical for the industry, which would be about 3 million dollars for a 270,000 barrel storage tank.[60] This amount of storage should be adequate for most unanticipated turnarounds. We presumed that half of refiners would need to add such storage, the other half of refineries either already having such storage available, have the capability to send the untreated blendstock to a nearby refinery which had spare capacity for treating this high sulfur blendstock, or would downgrade the high sulfur highway diesel batch to the high sulfur diesel pool (there is already a significant amount of highway diesel fuel sold as off-highway diesel fuel).[k] Adding such a storage tank to the typical refinery adds about 0.17 c/gal to the cost of desulfurizing diesel fuel for that refinery.

The cost inputs for the storage tank and the finishing reactor are summarized in Table V.C-12.

[k] Presuming that half of refineries will add a storage tank is reasonable, because some refineries will not need to add a storage tank due to blendstock shifting and downgrading options to them, and that some will have to install such a tank since they will not have such options available to them.

Table V.C-12. Process Operations Information for Additional Units used in the Desulfurization Cost Analysis

	Diesel Storage Tank	***Distillate Hydrocracker Post Treat Reactor***
Capacity	50,000 bbls	25,000 (bbl/day)
Capital Cost (MM$)	0.75	5.7[61]
Electricity (KwH/bbl	---	0.98
HP Steam (Lb/bbl)	---	4.2
Fuel Gas (BTU/bbl)	---	18
Cooling Water (Gal/bbl)	---	5
Operating Cost ($/bbl)	none*	---

* No operating costs are estimated directly, however both the ISBL to OSBL factor and the capital contingency factor used for desulfurization processes is used for the tankage as well, which we believe to be excessive for storage tanks so it is presumed to cover the operating cost.

Refiners will also likely invest in a diesel fuel sulfur analyzer.[62] The availability of a sulfur analyzer at the refinery would provide essentially real-time information regarding the sulfur levels of important streams in the refinery and facilitate operational modifications to prevent excursions above the sulfur cap. Based on information from a manufacturer of such an analyzer, the cost for a diesel fuel sulfur analyzer would be about $50,000, and the installation cost would be another $5000.[63] Compared to the capital and operating cost of desulfurizing diesel fuel, the cost for this instrumentation is far below 1 percent of the total cost of this program.

i. Capital Cost Adjustment Factors

Capital costs are the one-time costs incurred by purchasing and installing new hardware in refineries. The capital costs supplied by the vendors, as discussed above, were designated to apply for a particular volumetric capacity in 1999 dollars. These costs are adjusted to match the volume of the particular case being analyzed using the "sixth tenths rule."[1] According to this rule commonly used in the refining industry, the capital cost of a smaller or larger piece of equipment varies in proportion to the ratio of the smaller or larger capacity to the base capacity taken to some power, typically 0.6.

The calendar day volume is increased by 20 percent to size the hydrotreating unit for stream days which are the days which the unit is operating. This 20 percent calendar day to stream day factor is used to size the new hydrotreater to account for changes in day-to-day operations, for the difference in diesel fuel production throughout the year, and for treating offspec batches.

The capital costs are adjusted further to account for the offsite costs and differences in labor costs relative to the Gulf Coast. The factors for calculating the offsite costs and accounting for differences in labor costs is taken from Gary and Handewerk.[64] The offsite and labor factors from Gary and Handewerk are provided for different refinery sizes and different parts of the country, respectively. For the Tier 2 gasoline sulfur rule they were calculated for each PADD and we summarized those cost factors in Table V.C-13. The offsite factor provided by Gary and Handewerk is for a new desulfurization unit, but offsite costs are much lower for a revamped unit. We cut those factors in half to account for those units which are revamps of existing units.[65] The PADD-specific and national average cost factors are summarized in Table V.C-13 below.

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[1] The capital cost is estimated at this other throughput using an exponential equation termed the "six-tenths rule." The equation is as follows: $(Sb/Sa)^e xCa=Cb$, where Sa is the size of unit quoted by the vendor, Sb is the size of the unit for which the cost is desired, e is the exponent, Ca is the cost of the unit quoted by the vendor, and Cb is the desired cost for the different sized unit. The exponential value "e" used in this equation is 0.9 for splitters and 0.65 for desulfurization units (Peters and Timmerhaus, 1991).

Table V.C-13. Offsite and Location Factors Used for Estimating Capital Costs

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5*
Offsite Factor - New Unit	1.26	1.26	1.20	1.30	1.30
- Revamped Unit	1.13	1.13	1.10	1.15	1.15
Location Factor	1.5	1.3	1	1.4	1.2

To account for other capital costs not accounted for by this cost estimate, such as some refiners having to debottleneck the amine and sulfur plants to address the additional sulfur removed and for other contingencies, capital costs were increased by 15 percent, a typical factor used for this type of analysis.[66] In addition, we modified this contingency factor based on comments which we received since the NPRM. The Association of Automobile Manufacturers provided comments on a cost study by the Department of Energy which estimated the cost of desulfurizing diesel fuel. These comments, made by an oil industry consultant, provided information on typical oil industry cost factors for starting up and operating new units in refineries percent.[67] One such cost factor is that the oil industry incurs a cost to start up a new unit which corresponds to about 3 percent of total capital costs. This factor was incorporated into our analysis by increasing our contingency factor from 15 to 18 percent.

The economic assumptions used to amortize capital costs over the production volume of low sulfur highway diesel fuel are summarized below in Table V.C-14.[68] These capital amortization cost factors are used in the following section on the cost of desulfurizing diesel fuel to convert the capital cost to an equivalent per-gallon cost.[m]

[m] The capital amortization factor is applied to a one time capital cost to create an amortized annual capital cost which occurs each and every year for the 15 years of the economic and project life of the unit.

Table V.C-14. Economic Cost Factors Used in Calculating the Capital Amortization Factor

Amortization Scheme	*Depreciation Life*	*Economic and Project Life*	*Federal and State Tax Rate*	*Return on Investment (ROI)*	*Resulting Capital Amortization Factor*
Societal Cost	10 Years	15 Years	0 %	7%	0.11
Capital Payback	10 Years	15 Years	39 %	6% 10%	0.12 0.16

ii. Fixed Operating Costs

Operating costs which are based on the cost of capital are called fixed operating costs. These are fixed because these costs are normally incurred whether or not the unit is operating or shutdown. Fixed operating costs normally include maintenance needed to keep the unit operating, buildings costs for the control room and any support staff, supplies stored such as catalyst, and insurance. The comments from the oil industry consultant referred to above were useful here for updating this portion of our analysis.

Various fixed operating cost factors were estimated based on comments which we received from the American Automobile Manufactures consultant referred to above.[69] Maintenance costs are estimated to be 3 percent of final capital costs. Other fixed operating costs are 1.5 percent of capital costs for buildings, 0.2 percent for land, one percent for supplies which must be inventoried such as catalyst, and 1 percent for insurance. These other fixed operating cost factors sum to 3.7 percent and, when combined with the 3 percent maintenance cost factor, sum to 6.7 percent. This total fixed cost factor of 6.7 percent is applied to the final capital cost (after including offsite costs and adjusting for location factor) to generate an annual fixed operating cost.

Annual labor costs are also estimated using the cost equation in the Oak Ridge National Laboratory (ORNL) refinery model. Labor cost is very small, on the order of one thousandth of a cent per gallon.

iii. Utility and Fuel Costs

Variable operating costs are those costs incurred to run the unit on a day-to-day basis, and are based completely on the unit throughput. Thus, when the unit is not operating, variable operating costs are not being incurred. Here, variable operating costs are determined using annual average diesel fuel production volumes instead of refinery specific production volumes to avoid over- and under-counting of production when specific units are processing stored distillate after a shutdown or downgrading product when a unit is shutdown. The operating cost demands (utilities, hydrogen, and yield loss) are based on estimates from the desulfurization technology licensors described above. The basis for the values is 98 percent desulfurization (340 ppm sulfur reduced to 7 ppm sulfur on average) of the highway pool.

The utility cost inputs for our refinery model are from 1999 Energy Information Administration (EIA) information for each of the five Petroleum Administrative Districts for Defense (PADDs).[70]

Yield loss is based on the volume of diesel volume lost times its market price offset by the additional volume of other products produced times their sales for resale market prices. A representative refinery price for diesel fuel after the desulfurization programs begins is derived by adding the estimated cost of desulfurizing diesel fuel for the highest cost producer to the resale price for diesel fuel from EIA. These cost factors are summarized in Table V.D-15.

Fuel gas is consumed in running furnaces for heating up streams including the reboilers used in distillation. Fuel gas cost is based on an estimation factor which is three dollars per million British thermal units (BTU) for PADD 3,[71] one quarter higher than that for PADDs 1, 2 and 5, and half higher for PADD 4. Steam demand is converted to BTU demand on the basis that it is 300 pound per square inch (psi) steam, and that demand is presumed to be met with fuel gas, however, we increase the cost by a factor of two which is consistent with published cost estimation methodology.[72] Producing steam is presumed to demand 809 BTU per pound of steam required.

Hydrogen costs are assumed to vary by PADD. The cost of hydrogen supply was estimated for PADD 3, and then increased for other PADDs that typically have higher costs. Hydrogen cost for PADD 3 is based on an average of refiners putting in their own hydrogen plants, which could cost as much as three dollars per thousand standard cubic foot (MSCF), and purchasing hydrogen as a commodity from a large hydrogen plant at a little more than one dollar per MSCF.[73] Based on this range of possible cost, PADD 3 would be expected to have access to hydrogen supplied at a cost of about two dollars per MSCF. PADD 4 is assumed to have to pay the more conservative cost of three dollars per MSCF, and the other PADDs are assumed to incur a cost between PADDs 3 and 4, which would be $2.5 per MSCF. This analysis does not consider numerous other possibilities of providing hydrogen at a reduced cost by using hydrogen recovery technology (which would recover hydrogen from plant gas), or by increasing hydrogen production from the reformer by converting high pressure reformers to low or ultra low pressure reformers.

Table V.C-15. Summary of Costs From EIA Information Tables for 1999,* and Other Cost Factors

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5*
Electricity (c/KwH)*	8.35	6.40	6.66	5.4	7.18
LPG ($/Bbl)*	17.09	14.11	14.49	14.53	17.05
Highway Diesel (c/gal)*	53.1	55.9	51.5	62.4	64.0
Nonhighway Diesel (c/gal)*	49.3	55.7	48.6	60.4	58.9
Gasoline ($/Bbl)*	27.0	25.9	24.9	28.9	30.0
Fuel Gas ($/MMbtu)	3.75	3.75	3.0	4.5	3.75
Hydrogen Cost ($/MSCF)	2.5	2.5	2.0	2.0	2.5

* c/KwH is cents per kilowatt-hour, $/Bbl is dollars per barrel, c/gal is cents per gallon, $/MMbtu is dollars per million British Thermal Units (Btu), $/MSCF is dollars per thousand standard cubic feet.

Similar to the capital costs, we added a 10 percent operating cost safety factor to account for other operating costs which are beyond the operating cost of the desulfurization unit.[74] This factor accounts for the operating cost of processing additional hydrogen sulfide in the amine plant, additional sulfur in the sulfur plant, and other costs which may be incurred but not explicitly accounted for in our cost analysis. We then increased this factor by 2 percent to account for reprocessing of offspec material. For estimating capital costs, we estimated that 5 percent of the batches would be offspec and could not be blended down with lower sulfur product. However, since this material was desulfurized once already, the operating costs for reprocessing it would be much lower the second time around.

We also believe that refinery managers will have to place a greater emphasis on the proper operation of other units within their refineries not just the new diesel fuel desulfurization unit, to consistently deliver very low sulfur highway diesel fuel under the proposed cap standard. For example, meeting a stringent sulfur requirement will require that the existing diesel hydrotreater and hydrocracker units operate as expected. Also, the purity and volume of hydrogen coming off the reformer and the hydrogen plant would be important for effective desulfurization. Finally, the main fractionator of the FCC unit would have to be carefully controlled to avoid significant increases in the distillation endpoint, as a significant volume increase in sterically hindered compounds could be sent to the diesel hydrotreater with an increase in endpoint. The diesel hydrotreater may not be designed to desulfurize a significant increase in sterically hindered compounds. Improved operations management to control each of these units or situations could involve enhancements to the computer systems which control the refinery operations, as well as improved maintenance practices.[75] Refiners may be able to recoup some or all of these costs through improved throughput. However, even if they cannot do so, these costs are expected to be less than 1 percent of those estimated below for diesel fuel desulfurization.[76] [77] No costs were included in the cost analysis for these potential issues.

f. Future Diesel Fuel Volumes

The volume of diesel fuel produced in future years is expected to increase consistent with projected future increases in diesel fuel demand. Estimating this increase is important as both the per-gallon costs and the aggregate costs are affected by the increase. Ignoring inflation and assuming that the prices of raw materials and products stay the same as in 1999, per-gallon costs would decrease somewhat with slightly improved economies of scale. However the aggregate capital and operating costs would increase as production volumes increase, although this increase is slower than the rate of increase in demand due to economies of scale.

To project future diesel fuel consumption, we relied on projections from the Energy Information Administration (EIA). EIA projects consumption of refined products into the future based both on historical production trends and on market factors likely to affect future demand. In the year 2000 Annual Energy Outlook, EIA projects that in 2006, highway diesel fuel consumption will be 39.5 billion gallons per year, with imports of 2.0 billion gallons per year. This level of diesel fuel consumption is 12.6 percent higher than today's consumption volume.

Since our analysis is performed on a refinery-by-refinery basis, it is important to project how each refinery's production of highway diesel fuel will change as consumption increases. Refiners tend to invest capital dollars in their refineries periodically for increasing the production volume of their products. This process of increasing refinery throughput is called debottlenecking. However, we have no way to project which refiners will invest to debottleneck their refineries for increased production, thus we cannot assign increases to specific refineries. Instead, we assume that each refinery will increase their production of highway diesel fuel by the same 12.6 percent between now and 2006. While highway diesel fuel consumption would be expected to increase again between 2006 and 2010, the change is modest, so we assumed that the 2006 volumes would apply in 2010 as well.

We made no changes in the volumes of diesel fuel processed to account for changes in wintertime blending of kerosene. Our cost projections are based on the volume of highway diesel fuel consumed today projected to the year 2006 and this assumes no changes in that volume in our final rule.[n] Thus, our cost projections include hydrotreating that volume of

[n] Actually, we assume that the total energy consumed in the form of diesel fuel remains constant. Diesel fuel volume consumed increases slightly because of a small decrease in the energy content of diesel fuel after additional hydrotreating.

kerosene which is currently blended into winter diesel fuel. Some of the kerosene which is blended into winter diesel fuel is blended at the refinery. This kerosene should be able to be added prior to the hydrotreater and desulfurized along with the rest of the highway diesel fuel pool. The rest of this kerosene is added at terminals or at other points within the distribution system. If this practice were to continue, then the kerosene distributed to these points would also have to meet the sulfur cap. Given this would likely involve hydrotreating more kerosene than actually needed to winterize diesel fuel, we believe that this practice would become much less common. Instead, we believe that cold flow additives would be used in greater amounts in lieu of kerosene blending downstream of the refinery. Cold flow improving additives are commonly used today in economic competition with kerosene blending and we believe that the cost differential between desulfurizing kerosine and blending in cold flow additives to achieve the same effect is negligible. Thus, assuming that the difference in cost of cold flow additives and kerosene blending is negligible, we expect that diesel fuel suppliers would reduce the current amount of kerosene blending and increase additive use at no additional cost and avoid the need to hydrotreat kerosene which may be used in other applications than highway diesel engines to less than 15 ppm sulfur.

2. Projected Refinery Costs of Meeting the 15 ppm Sulfur Cap

For each of 121 refineries currently producing highway diesel fuel, the capital and operating cost inputs described above were combined together in our refinery model along with the fractions of the various blendstocks for each refinery to estimate the cost of desulfurizing highway diesel fuel from a base sulfur level of 340 ppm to an average of 7 ppm sulfur to meet the 15 ppm cap standard.[o]

The per-refinery capital and operating costs, and the per-gallon cost for refineries were classified into small and non-small refinery categories and are summarized in Table V.C-16 below.

[o] Grass roots capital costs were determined based on new equipment required while grass roots operating costs were assumed to be the same as a revamped unit.

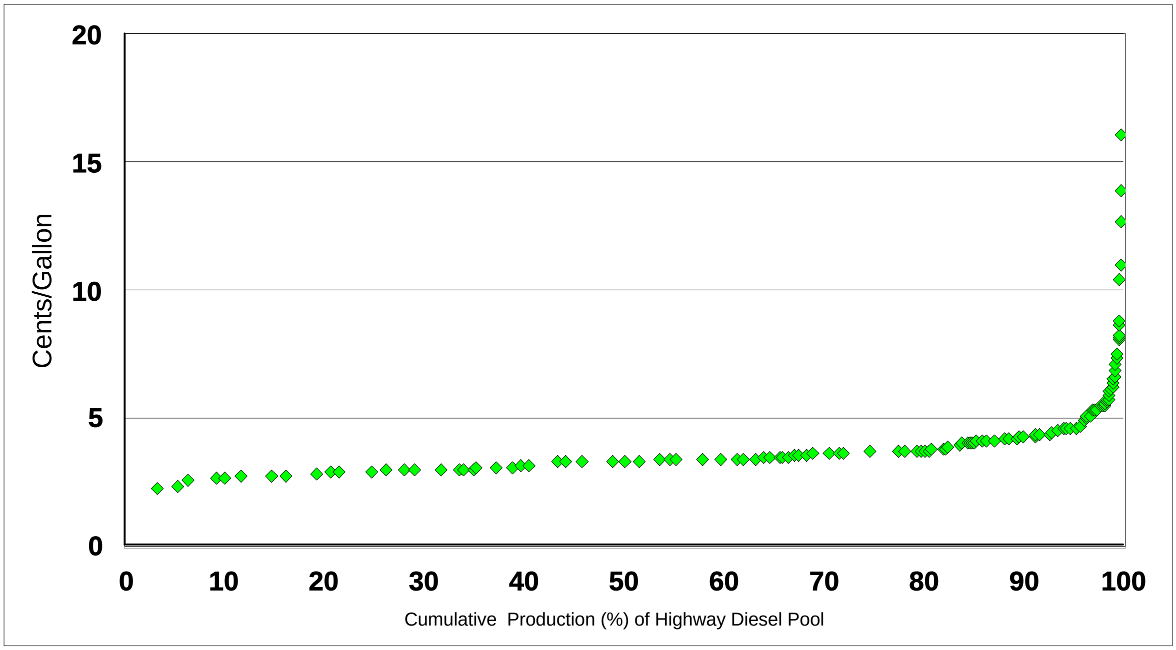
Table V.C-16. Estimated Per-Refinery Capital, Operating and Per-Gallon Cost for Full [A] Implementation of Desulfurizing Highway Diesel Fuel to Meet a 15 ppm Cap Standard (1999 Dollars, 7% ROI before taxes)

	Average of Nonsmall Refineries	*Average of Small Refineries*	*National Average*
Capital Cost ($Million)	52	14	44
Operating Cost ($Million/yr)	9.6	0.5	7.9
Per-Gallon Cost (c/gal)	4.2	5.0	4.3

[A] Based on the assumption that each refineries costs will be comprised of; 80% for revamping a refiner's existing hydrotreater unit and 20% for building a new grassroots unit. Grass roots units capital costs were determined based on new equipment required while grass roots operating cost were assumed to be the same as a revamped unit. National average refinery costs includes refineries classified as small. Capital costs are total aggregate per refinery in each category.

Table V.C-16 shows that, on average for full implementation of the15 ppm highway diesel fuel sulfur cap standard, non small refineries would incur initial capital cost of $52 million to meet the proposed sulfur cap. In addition, these refineries would incur an average of $9.6 million per year in operating costs. The capital and operating cost for typical small refineries would be much lower, $14 million and $0.5 million per year per refinery, respectively, but due to poorer economies of scale their installed capital costs would be higher on a per-gallon basis. Our cost estimates bear this out as the per-gallon cost to the average small refinery is about 20 percent higher (about 1.0 cents per gallon) than the per-gallon cost of the average nonsmall refinery, thus, our analysis projects that small refineries are more challenged than the refineries which treat a larger volume of diesel fuel. The per-gallon cost for all of the refineries participating varied and can be viewed in Figure V.C-1. Inspection of the graph reveals that for the 121 refineries, only four to five volume percent of the total highway pool have high costs that exceed 5 cents per gallon.

Figure V.C-1. Refinery Specific Costs for Fully Implemented 15 ppm Sulfur Cap Standard



[a] Costs per treated volume of highway diesel for 121 refineries, 1999 dollars and capital is amortized 7% ROI before taxes.

Refineries with LCO and coker gas oils had higher costs than those processing straight run diesel. LCO feed stocks had the highest hydrotreater costs with an average feedstock based incremental cost of 6.55 cents per gallon treated. Likewise, coker gas oil and straight run diesel had average incremental feedstock costs of 4.72 and 3.47 cents per gallon, respectively. The costs for LCO and coker feed stocks were higher due to the increased capital and operating cost associated with treating these feed stocks, see Table V.C-17.

Table V.C-17. Costs for Treating LCO, Coker, and Straight Run Diesel Feedstocks (1999 Dollars and 7% before tax ROI)

	LCO [a]	*Coker* [a]	*Straight Run Diesel* [a]
Cost to Treat Feedstock c/gal	6.55	4.72	3.47

[a] Based on the assumption that each refinery's costs will be comprised of; 80% for revamping a refiner's existing hydrotreater unit and 20% for building a new grassroots unit. Grass roots units capital costs were determined based on new equipment required while grass roots operating costs were assumed to be the same as a revamped unit.

In Chapter 4, we discussed the temporary compliance option and small refinery hardship provisions with respect to refineries initiating compliance to the new highway diesel sulfur cap standard in either year 2006 or 2010. The refining industry is expected to take advantage of the temporary compliance option with the lowest cost producers complying during 2006-2009 and the highest cost producers complying starting in 2010. In each PADD for year 2006, the lowest cost refineries were added to the 2006 year pool until the volume requirement was meet for producing 80% of the respective PADDs' 15 ppm temporary compliance sulfur diesel pool. In addition, for each PADD, small refineries with costs that placed them in the 80% low cost temporary compliance pool were considered to enter the market in year 2006. Cost for 2006 also included small refineries that were projected to select the potion that allows extending the implementation date of the Tier 2 gasoline sulfur requirement. All remaining refineries which were not classified as being in the 2006 year pool were considered to comply in year 2010.

Table V.C-18. Overall Estimated Per-Refinery Capital, Operating and Per-Gallon Cost for Years 2006 and 2010 for Implementation of Desulfurizing Highway Diesel Fuel to Meet a 15 ppm Cap Standard (1999 Dollars, 7% ROI before taxes)

	Year 2006 Average Refinery [a]	*Year 2010 Average Refinery* [a]
Capital Cost ($Million)	61	24
Operating Cost ($Million/yr)	11.8	6.41
Per-Gallon Cost (c/gal)	4.1	5.0

[a] Based on the assumption that each refinery's costs will be comprised of 80% of the cost for revamping the refinery's existing hydrotreater unit and 20% for building a new grassroots unit. Grass roots units capital costs were determined based on new equipment required while grass roots operating costs were assumed to be the same as a revamped unit.

Our analysis of the average refinery capital, operating costs and average per gallon cost is summarized in Table V.C-18. On average, the 63 refineries entering the year 2006 pool would have capital costs of $61 million per refinery. The average capital costs for refineries that newly enter the 15 ppm highway pool in year 2010 are $24 million per refinery. These costs reflect that the large refineries have lower overall costs due to economies of scale and will enter the highway diesel market in year 2006. By delaying the revamp costs for the highest cost diesel hydrotreater units until 2010 the refinery industry will be able to defer $1.4 billion dollars over a four year period.

Table V.C-19 shows the aggregate capital and operating costs for the U.S. refining industry that were developed for 2006-2030. To calculate the aggregate capital cost, the total capital cost for each of the 121 refineries which we estimated in our refinery model was summed together. With the temporary compliance option and small refinery hardships provisions, capital costs for the years of 2006 and 2010 were $3.9 and $1.4 billion, respectively. Capital costs for complying in years 2006 and 2010 were spread to reflect project installation according to the following; one third of the capital costs assigned to the one year period before the compliance date with the remaining two thirds costs assigned to the two year period before the compliance date. Capital costs which are estimated to total $5.3 billion are presumed to be incurred in 2004, 2005, 2006, and 2008, 2009, and 2010 as the desulfurization units are installed in the refineries. To maintain future program compliance requirements, a second round of capital cost investments is assumed to occur 15 years later as the desulfurization units installed are replaced at the presumed end of their useful life. Aggregate capital costs increase for the 2nd round of investment in 2019 - 2025 relative to 2004 - 2010 due to increased fuel production volumes required to meet growth in diesel demand. We then calculated the yearly aggregate operating costs based on the projected diesel consumption in 2006-2030 shown in Table V.C-19. The aggregate operating cost is calculated by simply multiplying the average per-gallon operating cost and the aggregate volumetric consumption together. The aggregate operating costs increase each year due to the constant increase in growth in diesel demand. These costs are summarized in Table V.C-19.

Table V.C-19. Projected U.S. Aggregate Operating and Capital Cost of Desulfurizing Highway Diesel Fuel to Meet a 15 ppm Cap Standard (1999 Dollars, 7% ROI before taxes)

Year	*Projected 7 ppm Diesel Fuel Production[a] (Billion Gals)*	*Projected Aggregate Operating Cost ($Billion)*	*Projected Aggregate Capital Cost ($Billion) [a]*	*Projected Total Aggregate Cost ($Billion)*
2004	-		1.3	1.30
2005	-		1.9	1.90
2006	39.5*0.58	0.64	0.7	1.34
2007	40.1	1.04	-	0.75
2008	40.7	1.05	0.5	1.55
2009	41.3	1.07	0.7	1.77
2010	41.9	1.11	0.2	1.31
2011	42.6	1.13		1.02
2012	43.2	1.15		1.04
2013	43.8	1.17		1.05
2014	44.5	1.18		1.07
2015	45.2	1.20		1.09
2016	45.8	1.22		1.10
2017	46.5	1.24		1.12
2018	47.2	1.26		1.14
2019	47.9	1.27	1.5	2.77
2020	48.7	1.30	2.2	3.5
2021	49.4	1.31	0.8	2.11
2022	50.1	1.33		1.20
2023	50.9	1.35	0.6	1.95
2024	51.6	1.37	0.8	2.17
2025	52.4	1.39	0.3	1.69
2026	53.2	1.42		1.28
2027	54.0	1.44		1.30
2028	54.8	1.46		1.32
2029	55.6	1.48		1.34
2030	56.5	1.50		1.36

[a] For U.S. refiners only.

Table V.C-19 shows that the aggregate capital cost for complying with the proposed 15 ppm highway diesel sulfur cap is expected to total about $5.3 billion spread out over seven years. This level of capital expenditure is estimated to be slightly more than the capital expenditures expected to be made by the U.S. refining industry for complying with gasoline sulfur standards, (see Section B of Chapter IV). We believe that these costs are not excessive. For example, during the early nineties the U.S. refining industry invested over twenty billion dollars in capital for environmental controls for their refining and marketing operations; [85] this cost represented about one half of the total capital expenditures made by refiners for the downstream operations of their refineries. Considering the effects of inflation we believe that a program requiring the refining industry to spend about $5.3 billion is not overly burdensome from an economic perspective. The relative value of the costs and benefits of this program are discussed in Chapter VII.

As stated above, we also estimated the per-gallon cost of this program based on different capital cost amortization premises. In Table V.C-20 below, projected average per-gallon costs of complying with the proposed sulfur cap for small refineries and non-small refineries are shown based on various rates of return on investment (ROI) before taxes. The first row of costs shown are our estimates of the costs to society, which utilize a seven percent before tax ROI. We then present two additional cost estimates which are based on six and ten percent after tax ROIs. These latter rates of return are indicative of the economic performance of the refining industry over the past 10-15 years.

Table V.C-20. Per-Gallon Cost for Desulfurizing Highway Diesel Fuel to Meet a 15 ppm Cap Standard Based on Different Capital Amortization Rates (1999 Dollars)

	Average Cost of Non Small Refineries [a] (c/gal)	*Average Cost of Small Refineries (c/gal)*	*U.S. Average Cost (c/gal)*
Societal Cost 7% ROI before Taxes	4.2	5.0	4.3
Capital Payback (6% ROI, after Taxes)	4.3	5.2	4.4
Capital Payback (10% ROI, after Taxes)	4.6	5.8	4.7

[a] Average refinery costs excludes refineries classified as small.

In Chapter 4, we addressed the ability of the refining industry to produce adequate supplies of highway diesel fuel to avoid shortages under the 15 ppm highway diesel fuel cap standard. First, the temporary compliance option and small refinery hardship provisions substantially enhances supplies of highway diesel fuel by allowing roughly 22% of highway diesel fuel to continue to meet the 500 ppm cap. This gives roughly 58 refineries four more years before needing to invest in desulfurization equipment to meet the 15 ppm standard. By the time these refiners need to decide on a desulfurization technology, those units built in 2006 will have been operating for 1-2 years, providing commercial data upon which to conduct a comparison. This data will help these refiners to borrow money, if necessary, to pay for the new equipment.

The other factor easing highway diesel supplies is the ability of a number of refiners to economically produce 15 ppm fuel from current nonhighway diesel fuel blendstocks. To quantify this factor, we developed a model to estimate the cost to each refinery of desulfurizing all their existing nonhighway diesel fuel to an average sulfur level of 7 ppm (i.e., that needed to ensure compliance with the 15 ppm cap). These costs were developed for all U.S. refineries that currently produce nonhighway diesel. Especially in cases where grass roots refinery modifications are necessary to process current highway diesel fuel to 15 ppm sulfur, there are no competitive disadvantages, and in some cases improved economies of scale by investing to convert current nonhighway diesel to highway diesel. As was the case when estimating each refinery's cost to produce 15 ppm fuel from its highway diesel blendstocks, the cost for processing nonhighway diesel blendstocks were based on volume throughput and feedstock compositions. Again, as was done for their highway diesel blendstocks, each refinery's nonhighway blendstock composition was estimated from distillate pool information taken from the data provided by EIA for 1998 and 1999. These processing costs were reduced by using the average price differential between highway and nonhighway diesel fuel of EIA [83] and Muse Stancil & Co's [84] product pricing data. The EIA data was based on historical price difference between highway and nonhighway diesel fuel at the refinery gate while Muse Stancil & Co's pricing data was based on the historical price difference between low and high sulfur No. 2 Oil of batches being transported by pipeline to market. Using this average for credit is appropriate, since the highway diesel fuel produced from nonhighway diesel blendstocks would command the price of highway diesel fuel under the new sulfur cap, compared not to the price of highway diesel fuel prior to the cap, but to the price of nonhighway diesel fuel prior to the cap. See Table V.C-21.

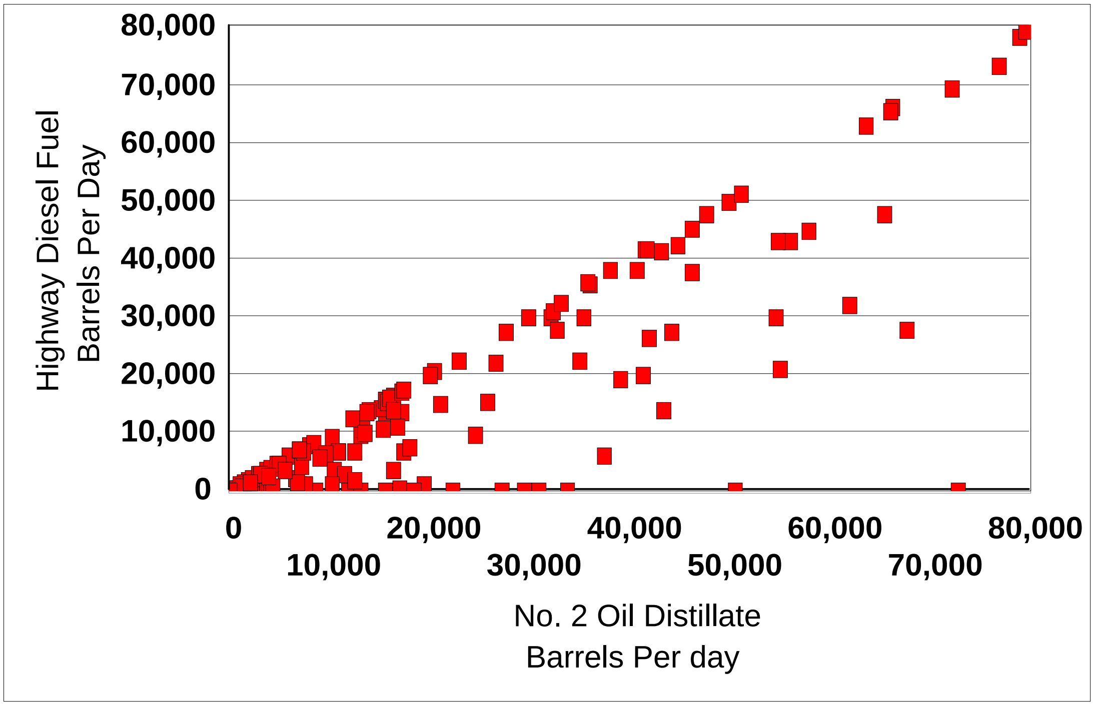
Table V.C-21. PADD-Average Price Difference Between 500 ppm Highway and Non-Highway Diesel (1999 Dollars, 7% ROI before taxes)

	Muse, Stancil's [a] Delta Price Between Low and High Sulfur No. 2 Oil (c/gal)	*EIA [a] Delta Price Between Highway and Nonhighway Diesel (c/gal)*	*Average of EIA and Muse Stancil & Co's data (c/gal)*
PADD 1	2.0	1.6	1.8
PADD 2	0.0	1.8	0.9
PADD 3	2.8	1.6	2.2
PADD 4	2.1		2.1
PADD 5	3.9	5.0	4.5

[a] EIA data based on 1995-1999 average price difference between low and high sulfur diesel fuel. Muse, Stancil & Co. prices from Alternate Markets for Highway Diesel Fuel Components, September 2000 and are based on 1995-1999 average price difference between low and high sulfur No.2 Oil. Overall volume weighted highway and nonhighway diesel cost adjustment for USA PADD regions is 2.2 c/gal.

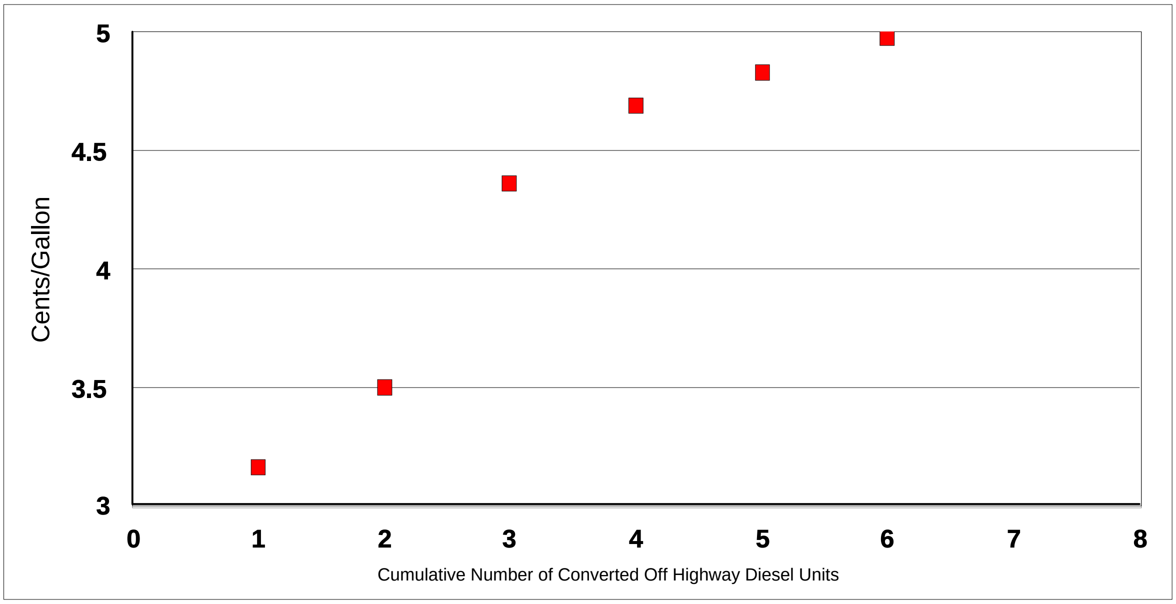
Through this analysis, we found that a number of refineries could produce highway diesel fuel from nonhighway diesel blendstocks in separate hydrotreating units at a cost which was competitive with other refineries in their PADD. In these cases, the volume of nonhighway diesel fuel was large so, regardless if the refineries are producing highway or not, we assumed that these would be new grassroots units. In our model, the nonhighway diesel blendstocks are processed in a new grass roots unit, while the highway diesel blendstocks are processed in either a revamped or grassroots unit, according to an 80:20 ratio. In reality, a refinery deciding to process both its highway and nonhighway diesel blendstocks to meet a 15 ppm cap would likely do so in a single grassroots unit sized to process both current products. We compared the cost of such a single larger grassroots unit to the two unit approach for a few refineries and found that the single grassroots unit would be less costly. Thus, the costs used in this analysis, which assume that the refinery would process its nonhighway diesel blendstocks in a separate unit, are likely to be slightly overestimated. For hydrotreater highway units with large volumes of highway and small volumes of nonhighway diesel, combining the two production streams as feed for revamping the existing hydrotreater would provide economies of scale and would reduce the overall costs in generating 15 ppm sulfur cap highway fuel. The costs used in this analysis did not consider this option. Figure V.C-2 illustrates that additional distillate volume would be available as feedstock to convert to highway diesel. Number 2 Oil in this figure is the summation of highway and nonhighway diesel fuel per refinery.

Figure V.C-2. Refinery Specific Production Rates of Highway Diesel versus No. 2 Oil Distillate Pool [a]



[a] Per Annum Refinery Specific plot of Highway Diesel Production volume versus total No. 2 Distillate volume produced by the refinery. Based on EIA refinery production data for 1998/1999.

Figure V.C-3. Lowest Refinery Costs for Converting NonHighway to 15 PPM Highway Diesel Fuel [A]



[A] Costs per treated volume of nonhighway diesel, 1999 dollars, and 7% ROI before taxes.

Overall, we found 2 refineries which produce essentially no highway diesel fuel today which could meet the new 15 ppm standard for less than 5.0 cents per gallon. Production from these refineries would increase nationwide highway diesel fuel production by 2 percent. We also found that 4 other refineries could increase production of highway diesel fuel from their nonhighway diesel fuel blendstocks for less than 5.0 cents per gallon. Production from these 4 refineries would increase highway diesel fuel production by an additional 5 percent. See Figure V.C-3 for plot of the cost of these nonhighway diesel fuel converted units.

A sensitivity analysis was then performed to estimate the cost of meeting the 15 ppm sulfur cap if some of the blendstocks currently being used to produce nonhighway diesel fuel were used to produce 15 ppm diesel pool and some of the refineries currently producing highway diesel fuel shifted their fuel to the nonhighway diesel fuel market.

We imposed a number of restrictions on such shifts. First, 15 ppm diesel fuel produced from nonhighway blendstocks used in PADDs 3, 4 and 5 had to be produced in those PADDs, with the further restriction that no such fuel could be transported to either Hawaii or Alaska from outside of those states. Second, 15 ppm diesel fuel produced from nonhighway blendstocks used in PADD 2 had to either come from within the PADD or could come from PADD 3 if it displaced higher cost highway diesel fuel in the southern portion of PADD 2. Practically, this limited any additional transfers of 15 ppm fuel from PADD 3 to PADD 2 to a very small amount (0.05 percent of current PADD 2 highway diesel fuel production). Finally, 15 ppm diesel fuel produced from nonhighway blendstocks in PADD 3 was allowed to displace current highway diesel fuel produced in PADD 1. PADD 3 currently sends sizeable amounts of both highway and nonhighway diesel fuel to PADD 1. The relative amount of highway diesel fuel produced in PADD 3 could therefore easily increase and the amount produced in PADD 1 decrease without changing the total volume of diesel fuel transported. We found that about 14% of current PADD 1 highway diesel fuel production could be made in compliance more economically from nonhighway diesel blendstocks in PADD 3. After considering these restrictions in the substitution of nonhighway to highway diesel fuel, only 5 percent of the total 15 ppm highway production volume is shifted to replace the high cost highway producers. This is less than the 7 percent of nonhighway diesel fuel which we found available with estimated costs less than 5 cents per gallon. Table V.C-22 highlights the cost difference between the nonhighway hydrotreaters and the highway producers which were supplanted by the nonhighway producers.

Table V.C-22. Costs Under Nonhighway Production Shift Scenario
(1999 Dollars, 7% ROI before taxes)

	Higher Cost Highway Units[a]	***15 ppm Diesel from NonHighway***
Number of Refineries	17	6
Capital Cost, Per Refinery ($Million)	12	29
Operating Cost, Per Refinery ($Million/yr)	1.5	2.5
Per-Gallon Cost (c/gal)	6.3	4.5

[a] Based on the assumption that each refinery's costs will be comprised of 80% of the cost for revamping the refinery's existing hydrotreater unit and 20% for building a new grassroots unit. Grass roots units capital costs were determined based on new equipment required while grass roots operating costs were assumed to be the same as a revamped unit.

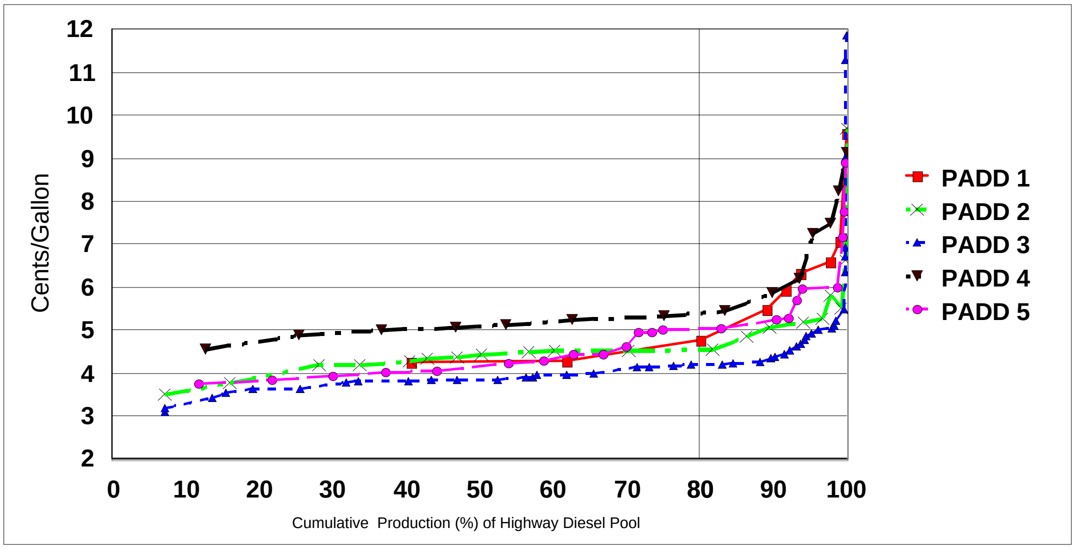
The effect of this shift on average costs and total capital cost are very small. These are shown in Table V.C-23. The effect of this shift on the maximum cost in each PADD is more significant, particularly in PADDs 1 and 5. In these PADDs, it would be very expensive to bring a very small percent of current highway diesel fuel production into compliance with the 15 ppm cap, primarily because of poor economies of scale. Refer to Section IV, Table IV.A-7 which compiles the PADD specific reduction in maximum costs attributed to using nonhighway to make 15 ppm sulfur cap highway diesel. With supplemental 15 ppm fuel from current nonhighway blendstocks, these small quantities of current highway fuel can be shifted to the nonhighway diesel fuel market with no loss of supply of highway diesel fuel or flooding of the nonhighway markets. Figures V.C-4 and V.C-5 illustrate the use of supplemental nonhighway to reduce maximum costs in each PADD. Figure V.C-4 represents the distribution of refinery cost by PADD for the case where production shifts were not presumed to occur between nonhighway and highway diesel producers. Whereas Figure V.C-5 represents a similar plot where production shifts are allowed. Comparing the two figures demonstrates that production shifts from nonhighway to highway would eliminate the highest cost producers. Both figures reveal that, for each PADD, costs are relatively constant for highway production volumes from 0 to 80 percent with the costs escalating for volumes greater than 80 percent. Inspection of the Figures also show that PADD 4 has the highest costs while PADD 3 has the lowest costs for producing highway diesel fuel which meets the 15 ppm sulfur cap standard.

Table V.C-23. Estimated Costs of Nonhighway Production Shift Scenario versus Current Highway Producer Scenario to Meet 15 ppm Highway Diesel Fuel Cap Standard (1999 dollars, 7% ROI before taxes)

	Nonhighway Units Shift Scenario [a]	*Current Highway Units Scenario*
U.S. Aggregate Capital Cost ($Billion)	5.4	5.3
U.S. Aggregate Operating Cost ($Million/yr)	970	960
Average Refinery Capital Cost ($Million)	51	44
Average Refinery Operating Cost ($Million/yr)	9.1	7.9
Average Per-Gallon Cost (c/gal)	4.2	4.3

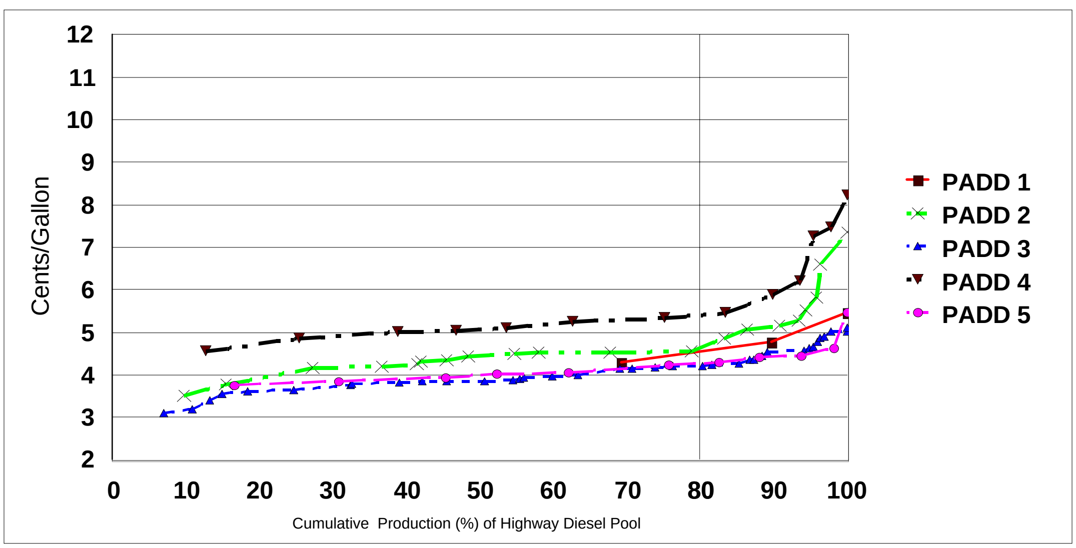
[a] Based on the assumption that each refinery's costs will be comprised of 80% of the cost for revamping the refinery's existing hydrotreater unit and 20% for building a new grassroots unit. Grass roots units capital costs were determined based on new equipment required while grass roots operating costs were assumed to be the same as a revamped unit.

Figure V.C-4. Refinery Costs per PADD for Current Highway Units Scenario for Meeting the 15 ppm Sulfur Highway Diesel Fuel Cap Standard [a]
(1999 dollars, 7% ROI before taxes)



[a] Costs excludes Hawaiian, Alaskan, and small refineries projected to take the gasoline extension option. Based on the assumption that each refinery's costs will be comprised of 80% of the cost for revamping the refinery's existing hydrotreater unit and 20% for building a new grassroots unit. Grass roots units capital costs were determined based on new equipment required while grass roots operating costs were assumed to be the same as a revamped unit.

Figure V.C-5. Refinery Costs per PADD under Converted NonHighway Units Shift Scenario for Meeting the 15 ppm Highway Diesel Fuel Cap Standard[a]
(1999 dollars, 7% ROI before taxes)



[a] Costs excludes Hawaiian, Alaskan, and small refineries projected to take the gasoline extension option.

a. Other Cost Estimates for Desulfurizing Highway Diesel Fuel

A number of cost estimates of the 15 ppm highway diesel fuel sulfur standard were submitted as part of the comments on the proposed rulemaking. Mathpro used a notional refinery model to estimate the national average costs of the proposed standard for the Engine Manufacturers Association (EMA). For the American Petroleum Institute (API), Charles River Associates, along with Baker and O'Brien, used the Prism refinery model to estimate the cost of U.S. refineries to produce highway fuel in the U.S. EnSys used the Oak Ridge National Laboratory PADD 3 refinery model to estimate costs for the Department of Energy(DOE). Finally, the National Petroleum Council (NPC) used the Mathpro refinery modeling work to estimate a cost for meeting a less stringent standard. The cost estimates from each of these studies is presented in the respective sections and, if appropriate, compared to our cost analysis.

Mathpro's Cost Analysis for EMA

In a study conducted for the EMA,[78] MathPro, Inc. estimated the cost of desulfurizing diesel fuel to meet a 15 ppm highway diesel fuel sulfur cap standard. MathPro assumed that desulfurization would occur entirely through severe conventional hydrotreating, and refining operations and costs were modeled using their ARMS modeling system with technical and cost data provided by Criterion Catalyst Company LP, Akzo-Nobel Chemicals Inc., and Haldor Topsoe, Inc. The resulting cost estimates were created based on what Mathpro terms a "notional" refinery. The notional refinery is configured to be typical of the refineries producing highway diesel fuel for PADDs 1, 2, and 3, and also represent the desulfurization cost for those three PADDs based on the inputs used in the refinery model. The Mathpro notional refinery model maintained production of highway diesel fuel at their base levels.

Mathpro made a number of estimates in their study to size their diesel desulfurization units for estimating the capital cost, and these estimates were similar to those included in our methodology. The calendar day volume was adjusted to stream day volume using a 10 percent factor to account for variances in day-to-day operations, and another 10 percent to account for variance in seasonal demand. In addition, Mathpro applied a factor which falls somewhere in the range of 1 - 8 percent for reprocessing off-spec material to meet a number of different sulfur targets. Since meeting a 15 ppm cap standard is a relatively stringent sulfur standard compared to the sulfur levels studied, Mathpro likely assumed the desulfurization unit would be sized larger by 5 - 8 percent. Onsite investment was adjusted to include offsite investment using a factor of 1.4. In the final report, capital costs were amortized at a 10 percent after tax rate of return.

There are several differences between our cost analysis and the cost analysis made by Mathpro. First, the MathPro costs are based on a 10 percent ROI after taxes. As stated above, our costs are calculated based on a 7 percent rate of return on investment (ROI) before taxes, so to compare our cost analysis with the cost analysis made by Mathpro, we adjusted the Mathpro costs to reflect the rate of return on capital investment which we use. Second, the Mathpro study did not attempt to project how much of highway diesel fuel will be produced by revamping existing diesel hydrotreaters versus installing new grassroots units. Instead, Mathpro provided cost estimates for both revamped and grassroots units. This range of costs is presented here, and we include a cost which represents 80 percent revamp and 20 percent grassroots units. Third, the MathPro estimate includes a cost add-on (called an ancillary cost) for reblending and reprocessing offspec diesel fuel or for storing nontreated diesel fuel. While this is conceptually an appropriate adjustment, it appears that some of the reblending costs in the MathPro study appear to be transfer payments,[p] not costs. Fourth, MathPro assumed that all new hydrogen demand is met with new hydrogen plants installed in the refinery, which does not consider the advantage of hydrogen purchased from a third party which can be produced cheaper in many cases. As a result, their hydrogen cost may be exaggerated, which would tend to increase costs. Finally, it should be noted that the MathPro study did take into consideration the need for lubricity additives, but did not address costs that might be incurred in the distribution system. Thus, in a comparison of our costs with Mathpro's, we will include our cost estimate for adding the appropriate amount of lubricity. A comparison of Mathpro's cost and our cost to desulfurize highway diesel fuel to meet a 15ppm sulfur cap standard is shown below in Table V.C-24.

Table V.C-24. Comparison of Mathpro's and EPA's Costs for Meeting a 15 ppm Highway Diesel Fuel Sulfur Cap Standard (7% ROI before taxes)

	Mathpro's Cost	*EPA's Cost*
Per-gallon Cost	4.2 - 6.1 (4.6)	4.3
Capital Cost	3.4 - 6.1 (3.9)	5.3

Cost assumes the addition of lubricity additives, but no distribution costs.

Lower end of the range in per-gallon costs assumes 100 percent revamped equipment; upper end assumes all new equipment; EPA costs and the Mathpro costs in parentheses assume 80 percent revamps and 20 percent new units.

Charles River and Baker and O'Brien Study for API

Charles River Associates and Baker and O'Brien (heretofore referred to as CRA), in a study for API, analyzed the impacts of a 15 ppm highway diesel fuel sulfur cap standard on the U.S. oil industry. Nonroad diesel fuel was also reduced to 350 ppm, probably to meet an assumed future 500 ppm cap standard. CRA used the Prism refinery model along with their own

[p] A transfer payment is when money changes hands, but no real resources (labor, natural resources, manufacturing etc.) are consumed.

estimates of hydrotreating costs to estimate the cost to each refinery of meeting the cap standard taking into account the estimated fractions of the various blendstocks which comprise highway diesel fuel and the quality of crude oil used by each refinery. CRA based their cost analysis on desulfurization technology (not on ring opening technology, and hydrogen consumption was similar to Mathpro's), but estimated that 40 percent of refiners would build new hydrotreating units with the balance of refiners revamping their existing units.

CRA surveyed the major refiners which produce about half of the total amount of highway diesel fuel produced in the U.S. asking if they anticipated producing highway diesel under a 15 ppm sulfur cap standard. Refiners responded with a range of responses. Some said that they would increase or maintain their highway diesel fuel production, while others said that they would decrease their production. CRA concluded from their analysis of the survey responses that highway diesel production would decrease by 9 to 11 percent. Since this was an estimated shortfall in domestic highway diesel fuel production associated with a lack on investment by a large number of refineries, only imports were presumed to be available to make up the difference.

CRA's estimates for sizing their diesel desulfurization units are summarized here. First, each unit size is increased by 20 percent to account for sizing a unit's calendar day volume to a stream day volume, which addresses variances in daily or seasonal highway diesel production output, and unit downtime. Then, CRA assumed, based on a study by Baker and O'Brien, that 10 percent of the highway diesel fuel being produced would be downgraded to nonhighway diesel due to contamination in the distribution system. To make up for that loss in volume, each refinery's diesel desulfurization unit size and the operating costs were increased by 10 percent to account for this projected volume shortfall. The unit size was increased by another 10 percent to account for reprocessing of offspec batches. Thus, after consolidating all these factors, each refinery unit was sized 40 percent larger than calendar day volume. Then, the calculated capital costs were adjusted upward by 20 percent to cover contingencies. In estimating per-gallon costs, CRA amortized the capital costs at a 10 after tax percent rate of return.

CRA did not directly provide an average cost estimate for their analysis, estimate an average cost from CRA's report, we examined CRA's cost curve which plots individual cost for each refinery in the U.S., which CRA assumes are continuing to produce highway diesel fuel, against cumulative highway diesel fuel production. The average cost for the U.S. refineries is about 6.2 c/gal. CRA did not attempt to determine a diesel desulfurization cost for the balance of the highway diesel fuel which would have to be made up by imports.

We have a couple of observations and comments on the analysis by CRI. First, the study incurred costs for desulfurizing nonroad diesel fuel to meet a 500 ppm cap standard, however, the study's report did not provide the reader with information to determine what impact desulfurizing nonhighway might of had on the per-gallon cost of desulfurizing highway diesel fuel. CRA assumed that this 500 ppm fuel would be produced by blending 8 ppm sulfur highway diesel fuel and 3000 ppm nonroad diesel or heating oil. While, much of this production was assumed to occur due to mixing in the distribution system, an unknown amount of 500 ppm fuel was produced at refineries. Desulfurization costs are not linear, as shown by CRA's own study. Thus, any blending of 15 ppm sulfur highway diesel fuel with non-desulfurized heating oil at refineries was much more costly than simply hydrotreating nonroad diesel fuel to 500 ppm.

Second, the cost study conservatively assumed that refiners would build their diesel desulfurization units 40 percent larger than their calendar day production volume. Our analysis assumed that the revamped or grassroots units would be sized 20 percent larger than the calendar day diesel fuel volume being desulfurized, and Mathpro assumed that the revamped and grassroots units would be sized 25 percent larger. Finally, the analysis did not attempt to estimate the likelyhood and did not estimate the cost of nonhighway diesel

On a more fundamental level, we doubt that the perspective of whether to invest or not held by the surveyed refiners might have had earlier this year, or even now, will necessarily be the perspective that they will have several years from now when construction of the new units will have to begin. For example, many of these refiners haven't had the chance to test their diesel fuel to really understand what their cost would be for desulfurizing their highway diesel fuel. As the development of catalysts progresses which vendors expect to occur over the next two or so years,[q] refiners may see that the difficulty and cost of meeting the cap standard is not as high as they once thought. Furthermore, these refiners would likely not make a firm decision on how they will invest at this point in time because they would need to better understand the plans of the rest of the refining industry. The temporary compliance option will give refiners insight on who will participate in the program and what their likely market share will be for distillate products. If refiners do not consider the intended actions of their fellow refiners, there is significant economic risk. Using this analysis as an example, if refiners invest in a way that would result in a shortfall of 12 percent in highway diesel fuel capacity, we estimate that there would be overproduction of nonroad diesel fuel by 20 percent. Those refiners which choose not to produce highway diesel fuel would see the price of nonroad diesel drop through the floor and their profits suffer accordingly. We do not believe that refiners would put themselves at that kind of risk.

Ensys for the Department of Energy

Ensys estimated the cost of desulfurizing highway diesel fuel for the Department of Energy (DOE). Ensys studied various levels of desulfurization, however, we will discuss the case which estimated the cost of averaging 8 ppm, which is about the level of sulfur control needed to meet the 15 ppm cap standard. Ensys only studied the cost of meeting the highway diesel fuel sulfur requirement in PADD 3. EnSys did not estimate how many refiners would

[q] Two vendors have announced higher activity desulfurization catalysts since the point in time that the CRI survey was completed.

build new desulfurization units and how many would modify their current hydrotreaters, but presented costs for doing either. Thus, the lower limits of the ranges shown in Table V.C-24 assume refiners will modify their current hydrotreaters, while the upper limits assume that refiners would build new units. EnSys also projected costs for two separate sets of technologies. One set was considered conservative and relied upon technology that is already in commercial use. EnSys' costs using the conservative technology are higher than our estimates. This is due to the fact that this technology involves greater capital investment and greater consumption of hydrogen, because this technology is not just designed to reduce sulfur, but to reduce aromatic content, increase cetane levels and perform some cracking. The second technology analyzed by EnSys was labeled as optimistic. We believe the technology assumed to be used in the optimistic case was similar to that projected to be used by EPA (as well as CRA and Mathpro) since Ensys developed these costs after we shared vendor information with Ensys. Ensys reported their costs based on a 10 percent after tax return on investment, however, in Table V.C-25 below, we adjusted the Ensys costs to a 7 percent ROI before taxes.

Ensys made the following estimates for sizing their diesel desulfurization units. Unit size based on calendar throughput was increased by 5 percent to account for unit downtime, then an additional 15 percent calendar to stream day factor was added on. Unit size was adjusted upward by another 15 percent as a "redundancy" factor to cover the processing of off-spec batches. The offsite battery limit capital costs for new units were 40 percent of the onsite battery limit costs, while revamp unit inside and offsite capital costs were 50 percent of new unit onsite and offsite costs. Ensys received comments on their modeling study by a refining industry consultant with Pricewaterhouse Coopers retained by the Association of Automobile Manufacturers. The consultant commented on a series of cost factors used in Ensys' refinery modeling study. Ensys estimated maintenance costs to be 3.5 percent of total capital costs, while the consultant explained that the maintenance cost typically is 2.5 - 3 percent of the refinery's replacement value. Ensys estimated taxes insurance and overhead to be 2% of total investment, while the refining industry typically experiences 0.5 to 0.7 percent for taxes and insurance. The consultant also recommended that three other factors, 3 percent for buildings, 7 percent for environmental and 10 percent for startup, be reduced by 50 percent.

Table V.C-25. Comparison of DOE and EPA Refining Costs for Meeting a 15 ppm Highway Diesel Fuel Sulfur Cap Standard (7% ROI before taxes)

	DOE Conservative Technology	*DOE Optimistic Technology*	*EPA*
Per-Gallon Cost (c/gal)	5.1 - 6.0 (5.3)	4.2 - 4.4 (4.2)	4.3
Capital Cost ($MM)	3.9 - 6.5 (4.4)	2.7 - 4.5 (3.1)	5.3

Lower end of the range in per-gallon costs assumes 100 percent revamped equipment; upper end assumes all new equipment; EPA costs and DOE costs in parentheses assume 80 percent revamps and 20 percent new units.
DOE costs are only for the Gulf Coast refining region, which have slightly lower per-gallon costs than the entire U.S., and about half the capital costs.

National Petroleum Council Study

At the request of the Secretary of Energy, the National Petroleum Council (NPC) studied the impact of various possible fuel programs on the industry's capability to continue to produce and distribute refined products, and maintain the viability of its refineries. The fuel programs studied by the NPC include desulfurizing gasoline, desulfurizing diesel fuel, eliminating MTBE from gasoline, and reducing the driveability index of gasoline. To carry out the study, the NPC established a committee comprised primarily of representatives of the oil industry, but representatives of the pipeline companies, engineering contractors, the Department of Energy, and the EPA participated as well. An important part of the study was to estimate the cost of the fuel programs being studied. The NPC estimated the cost for desulfurizing diesel fuel to meet an average sulfur standard of 30 ppm. Since the NPC did not study the cost of a 15 ppm cap standard, we cannot compare the NPC costs with our costs. However, it would still be useful to summarize those costs to get some indication of how an NPC cost for 15 ppm would compare to ours.

The NPC did not fund its own refinery modeling work. Instead, NPC relied upon the EMA-funded Mathpro cost analysis as the basis for its cost analysis. NPC concluded that it does not believe that the Mathpro study adequately captured the costs of achieving the very low sulfur levels included in some of the Mathpro study cases. While NPC admits that it could not review the vendor submissions on which Mathpro based its analysis, nevertheless, NPC concluded that the vendor data used was optimistic about achieving very low sulfur levels treating typical feedstocks which are eventually blended into highway diesel fuel. Consistent with its conclusion that the Mathpro analysis was optimistic, the NPC made a number of adjustments to the Mathpro cost analysis to provide its own cost analysis. Capital investments were increased by 20 percent. However, how hydrogen consumption was handled was less clear as early on in the report, hydrogen consumption and other operating costs were increased by 15 percent, but later on in the report the study described the adjustment for hydrogen consumption to be 20 percent. Also, the report stated that the offsite factor for the diesel desulfrization units were reduced from 1.5 to

1.4. Thus, assuming that both adjustments applied, there was a net increase in the investment costs of 10 percent. Mathpro modeled various refiner investment strategies which included the construction of a new unit and a revamp with another reactor in series. To meet a 30 ppm average sulfur standard, NPC assumed that half of highway diesel fuel would be desulfurized by a revamped unit, while the other half would be desulfurized with a new unit. After making these adjustments, NPC estimated that desulfurizing highway diesel fuel down to 30 ppm on average would cost 5.8 c/gal with capital costs amortized at a 10 percent after tax rate of return.

We have several comments on NPC's diesel cost analysis. First, NPC applied cost adjustment factors to increase the Mathpro cost analysis without having seen the vendor submissions. Also NPC adjusted Mathpro's cost estimates based on its assertion that the vendor's costs are overly optimistic. Even if NPC's adjustments factors correctly account for overoptimism in the vendor's estimate, they don't consider expected reductions in operating costs, and perhaps even capital costs, likely to occur as diesel desulfurization technology improves over time. Second, the considerations voiced above concerning Mathpro's modeled source and cost of hydrogen still apply for the NPC costs as well. Finally, NPC assumed 50-50 mix for revamps and new units which seems conservative for a moderate decrease in sulfur. NPCs mix of revamp and new units is much more conservative than the Charles River and Baker and O'Brien analysis for API. The analysis for API assumed a 40-60 mix for revamps and new units, respectively, however, for meeting a much more stringent 15 ppm cap sulfur standard.

3. The Added Cost of Distributing Low-Sulfur Fuel

a. Summary

Please refer to section IV.D. in this RIA for a detailed discussion of the changes that will need to take place in the highway diesel fuel distribution system as a result of our program. This section addresses the costs of these changes. The majority of the increase in distribution costs to adequately limit sulfur contamination during the distribution of 15 ppm diesel fuel are associated with an increase in the volume of highway diesel fuel that must be downgraded to a lower value product during transport by pipeline. There are also substantial costs associated with the need for additional storage tanks to handle two grades of highway diesel fuel during the initial period of our sulfur program when two grades of highway diesel fuel are allowed to be sold (15 ppm and 500 ppm sulfur cap highway diesel fuels).

We estimate that as a result of our sulfur program, distribution costs will increase by 0.5 cents per gallon of highway diesel fuel supplied when the sulfur requirements are fully effective beginning in the year 2010. During the initial years of our sulfur program (2006 through mid-2010) we estimate that the increase in distribution costs will be 1.1 cents per gallon of highway diesel fuel supplied. This estimate includes 0.7 cents per gallon for new storage tanks to handle two grades of highway diesel fuel (500 ppm and 15 ppm) during the initial years. For the sake of simplicity and to allow a comparison with distribution costs once the sulfur program is fully effective, the distribution costs during the initial years are also expressed in terms of the total volume of highway diesel fuel supplied. This includes 500 ppm as well as 15 ppm highway diesel fuel.

In the proposed rule, we estimated that distribution costs would increase by 0.2 cents per gallon if the proposed requirement that the entire highway diesel fuel pool meet a 15 ppm sulfur cap beginning in 2006 be adopted. This cost was comprised of roughly 0.1 cents per gallon due to an increased volume of highway diesel fuel downgraded to a lower value product during shipment by pipeline and additional terminal testing costs, and 0.1 cents per gallon for distributing the additional volume of highway diesel fuel needed due to an anticipated decrease in fuel energy density as a side effect of reducing the sulfur content to the proposed 15 ppm cap. The case evaluated in the Notice of Proposed Rulemaking (NPRM) is most similar to that for the fully effective sulfur program in the final rule.

We took advantage of additional information contained in the comments to the NPRM in formulating a more comprehensive estimate of the distribution costs for the final rule. In some cases this involved adjusting an estimate for a parameter that factored into our calculation of costs in the NPRM. One important example is that we increased our estimate of the additional volume of highway diesel shipped by pipeline that would need to be downgraded to a lower value product. This downgrade volume is primarily the result of mixing that occurs between highway diesel fuel and high sulfur products that are shipped in the pipeline adjacent to highway diesel fuel. This mixture is referred to as interface when it can be blended into another product and transmix when it must be returned to the refinery for reprocessing. In other cases, our reevaluation of distribution costs included the consideration of parameters that did not factor into the estimation of distribution costs in the proposed rule. For example, commenters to the NPRM brought to our attention that there would be additional costs associated with changes in the handling practices for interface volumes that result from shipments of highway diesel fuel and jet fuel or kerosene which abut each other in the pipeline. We also attributed some cost to account for the process of testing and optimizing the distribution system to limit sulfur contamination. This includes the cost for testing to evaluate potential sources of contamination, and for miscellaneous minor procedural and hardware changes that may be needed, but have yet to be identified.

There are a number of common factors in the estimation of distribution costs during the initial years of our program and after the sulfur requirements becomes fully effective, such as the increase in interface volumes for pipeline shipments of highway diesel fuel. However, there are other factors that are unique to the estimation of costs during the initial years of the program. The factors that cause distribution costs to differ during the period when both 15 ppm and 500 ppm fuels are available for highway use:

- Having a lesser volume of 15 ppm diesel fuel in the system during the initial years of the program reduces some of the direct costs associated with distributing 15 ppm fuel.

- Having an additional grade of highway diesel fuel in the system (500 ppm) during the initial years of our program creates additional pipeline interface volumes, and additional product downgrade costs. Having 500 ppm highway diesel fuel in the system during the initial years of our program also allows some opportunity for the pipeline interface volumes associated with the shipment of 15 ppm fuel and jet fuel or kerosene to be downgraded to 500 ppm diesel fuel rather than off highway diesel fuel. This will reduce the cost of making this downgrade.

- The need for additional storage tanks to handle an additional grade of highway diesel fuel when the optional compliance option program is available creates additional costs that must be accounted for during the initial years of our program.

Table V.C-26 on the following page presents a summary of the distribution costs during the initial years of our sulfur program and after the program becomes fully effective. The manner in which these costs were estimated is discussed in the following sections.

Table V.C-26. Distribution Costs During the Initial Years of Our Sulfur Program and After the Program Becomes Fully Effective

	Distribution Costs (cents per gallon of all highway diesel fuel supplied) [A]	
Cost Components	Fully Effective Sulfur Program (2010 and later)	Initial Period (2006 - 2010)
Cost to Distribute Additional Volume Needed to Compensate for Reduced Energy Density of 15 ppm Sulfur Highway Diesel Fuel	0.17	0.14
Cost to Downgrade Additional Volume of 15 ppm Sulfur Highway Diesel Fuel to a Lower Value Product During Transport by Pipeline	0.14	0.10
Increased Cost for the Current Volume of Highway Diesel Fuel that Must be Downgraded in the Pipeline System	0.09	0.08
Increased Cost to Downgrade the Interface Volume Between Pipeline Shipments of Highway Diesel Fuel and Jet Fuel or Kerosene to Off Highway Diesel Fuel	0.07	0.03
Cost of Increased Terminal Testing	0.002	0.002
Cost of Additional Tanks to Handle Pipeline Interface Between Shipments of Jet Fuel and 15 ppm Sulfur Highway Diesel Fuel	Completely amortized during the initial years of program	0.009
Cost to Downgrade the Interface Volumes Associated with Pipeline Shipments of 500 ppm Fuel During the Initial Years of Our Program	No Additional Cost	0.004
Cost of Additional Tanks at Refineries, Terminals, Bulk Plants, and Truck Stops to Handle Two Grades of Highway Diesel Fuel During the Initial Years of Our Program	Completely amortized during the initial years of program	0.7
Cost of Optimizing the Distribution System to Limit Sulfur Contamination[B]	**0.025**	**0.027**
Total	0.5	1.1

[A] During the initial years of our program, “all highway diesel fuel” includes 500 ppm highway diesel fuel as well as 15 ppm highway diesel fuel.

[B] Cost amortized over the first 15 years of our sulfur program (through 2020).

There were some instances where we recognized that the rule would cause some change to current industry practice, but we concluded that the associated costs would not be significant. In one such case, we acknowledged that tank-truck operators and other distributors of highway diesel fuel downstream of the pipeline may need to be more careful in their observance of current industry practices used to limit product contamination, but we estimated that this would not result in a significant increase in costs (see Section V.C.3.i.). In another such case, we recognized that the use of diesel fuel additives with a sulfur content above 15 ppm would likely be phased out gradually by marketplace forces resulting from our diesel sulfur program, but concluded that this would be accomplished without a significant burden (see Section V.C.3.j.).

Our response to the public comments on the NPRM related to the costs of our sulfur control program are contained in a separate Response to Comments (RTC) document.

b. Cost of Distributing the Additional Volume of Highway Diesel Fuel Needed to Compensate for a Reduction in Energy Density

The energy density of highway diesel fuel is expected to decrease as a side effect of reducing the sulfur content to meet the proposed 15 ppm cap. As a result of this reduction in energy density, an increased volume of diesel fuel will need to move through the distribution system to meet the same level of consumer demand. The cost of producing this additional volume is included in the calculation of refinery costs (see Section V.C.1.). The cost of distributing the additional volume of highway diesel fuel needed to compensate for the lower energy density of highway diesel fuel that meets a 15 ppm sulfur cap is estimated at 0.17 cents per gallon of highway diesel fuel supplied under the fully effective program. During the initial years of our program, this cost is estimated at 0.14 cents per gallon. This cost is 20 percent lower during the period when the temporary compliance option is available because approximately 80 percent of the highway diesel fuel pool is required to meet a 15 ppm sulfur cap during this period.[r]

In the NPRM, we estimated that the cost of distributing highway diesel fuel was equal to the difference in price at the refinery rack and the retail price. For the final rule, we based our estimate of distribution cost on a PADD by PADD evaluation of the difference in the price of highway diesel fuel at the refiner rack versus the retail price. The price differential for each PADD was weighted by the additional volume of fuel we anticipate will need to be produced in each PADD to arrive at an estimate of distributing the additional volume needed for the nation as a whole. Table V.C-27 provides a summary of the PADD-based values used in this calculation.

[r] See section V.C.3.k. in this RIA for a discussion of how the relative volumes of 15 ppm and 500 ppm highway diesel fuel vary over the period when the temporary compliance program is available.

Table V.C-27. Data Used to Calculate the Cost of Distributing the Additional Volume of Highway Diesel Fuel Needed to Compensate for a Reduction in Energy Density

PADD	Price at the Retail Pump[1] (cents / gallon)	Price at the Refinery Rack[A] (cents per gallon)	Retail -Refinery Rack Price (cents per gallon)	Additional Volume Needed (fraction of supply)[B]
1	68.8	55.5	13.3	0.034
2	68.6	56.9	11.7	0.035
3	65.5	54.0	11.5	0.035
4	75.8	66.7	9.1	0.034
5	80.0	62.9	17.1	0.033
National Average	71.7	59.2	12.5	0.034

[A] Average price, excluding taxes, over the five year period from 1995 - 1999. Energy Information Administration (EIA), Petroleum Supply Annual (PSA), 1995-1999. Five year average costs were used for the purpose of this calculation to provide an estimate of the typical difference between the price at the refinery rack and at the retail pump.
[B] Based on our estimate of the changes refiners will make to meet the 15 ppm sulfur cap for highway diesel fuel. See Section IV.A.

We believe the approach outlined above provides a more accurate estimate of costs. Since the difference in price at the refiner rack versus that at retail also includes some profit for the distributor and retailer, its use provides a conservatively high estimate of distribution costs. The fact that a slightly less dense (lighter, less viscous) fuel would require slightly less energy to be distributed also indicates that this estimate is conservative.

c. Cost of Downgrading an Increased Volume of Highway Diesel Fuel to a Lower Value Product During Shipment by Pipeline

We estimated that the volume of highway diesel fuel that is currently downgraded to a lower value product during shipment by pipeline is 2.2 percent of the total volume of highway diesel fuel supplied and that this volume would double to 4.4 percent due to the implementation of our sulfur control program. Please see section IV.D.2.a. for a discussion of how we arrived at this estimate. This section addresses the cost of the additional downgrade volume (2.2 percent) caused by our sulfur program. The cost to produce this additional volume is discussed in section V.C.2.

The cost of downgrading the increased volume of highway diesel fuel to a lower value product is based on the difference in the cost of 15 ppm sulfur diesel fuel and the product to which the interface is downgraded. When our program is fully effective, this downgrade will be made into the off highway diesel pool. The cost of this increased volume of downgrade when the program is fully effective is estimated at approximately 0.14 cents per gallon of highway diesel supplied under the fully effective program. The cost of this additional downgrade is somewhat less during the initial years of our sulfur program because of the ability to downgrade 40 percent of the additional downgrade volume to 500 ppm diesel fuel in those pipelines that we expect will carry 500 ppm diesel fuel[s]. The cost of the additional downgrade during the initial years of our program is estimated at 0.1 cents per gallon of highway diesel fuel supplied.

Following is a discussion of how we arrived at the above estimates.

There are two factors which influence the cost of making the downgrade of highway diesel fuel discussed above. The first is the volume of the amount of highway diesel fuel that must be downgraded. The second is the cost of making the downgrade based on the difference between the cost of highway diesel fuel and the product that it is being downgraded to.

When our sulfur program is fully effective, the cost of downgrading the additional 2.2 percent of highway diesel fuel to a lower value product is the 6.5 cents / gallon difference in the cost of producing a gallon of 15 ppm highway diesel fuel and that of producing a gallon of off highway diesel fuel.[t] To derive an estimate of the cost of this additional downgrade in terms of the total volume of highway diesel fuel supplied, 6.5 cents / gallon was multiplied by the additional fraction of the highway diesel pool that will need to be downgraded (0.022) to arrive at result 0.14 cents per gallon.

During the initial years of our program, there will be a smaller additional volume of highway diesel fuel that must be downgraded to a lower value product because some of the highway diesel pool will continue to be 500 ppm fuel. We estimated that approximately 80 percent of the highway diesel pool will be 15 ppm fuel during the initial years of our program.[u] This reduces the cost associated with the additional downgrade. The cost of the additional downgrade is also reduced during the initial years of our program because 40 percent can be downgraded to 500 ppm highway diesel fuel which is a higher value product than off highway diesel fuel. This is based on our estimate that 40 percent of the pipeline systems that carry

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[s] See section V.C.3.k. in this RIA for additional discussion regarding the extent to which we anticipate 500 ppm diesel fuel will be present in the distribution system..

[t] See section table V.C-20 and attending text in section V.C.2. for a discussion on the difference in the cost of producing 15 ppm highway diesel fuel and that of producing off highway diesel fuel.

[u] See section V.C.3.k. for a discussion on the relative volumes of 15 ppm and 500 ppm highway diesel fuel during the initial years of our program .

highway diesel fuel will carry both 15 ppm and 500 ppm highway diesel fuel.[v] We used our estimate of the cost of producing 15 ppm highway diesel fuel under the fully effective program relative to the cost to produce 500 ppm diesel fuel today (4.1 cents per gallon) in calculating the cost of downgrading 15 ppm highway diesel fuel to 500 ppm highway diesel fuel. This provides a conservatively high estimate, since production costs for 15 ppm are somewhat lower during the start up of the program.[w]

Based on the above inputs, we estimate that the cost of the additional downgrade will be 0.11 cents per gallon for the 40 percent of fuel distributed using the part of the system that handles both grades of highway diesel fuel, and 0.08 cents per gallon for the 60 percent of fuel that is distributed using the part of the system that carries only 15 ppm highway diesel fuel. By weighting these two results, we arrived at our over-all estimate of the cost of the additional volume of highway diesel fuel that will be downgraded to a lower value product of 0.1 cents per gallon of highway diesel fuel supplied.

d. Increased Cost of Downgrading the Current Interface Volumes Associated with Pipeline Shipments of Highway Diesel Fuel

We identified that there would also be an increase in the economic impact for the existing volume of interface currently associated with pipeline shipments of highway diesel fuel. This is because the cost of downgrading the existing interface volume would be determined by the difference between the cost of 15 ppm sulfur fuel and off highway diesel fuel rather than the difference in cost between current 500 ppm diesel fuel and off highway diesel fuel as it is today. We estimate that the increase in the cost of downgrading the existing highway diesel interface would be 0.09 cents per gallon of highway diesel fuel supplied during the fully effective program. During the initial years of our program, we estimate this cost at 0.08 cents per gallon of highway diesel fuel supplied. Following is a discussion of how we arrived at these estimates.

When our sulfur program is fully effective, all of the volume of highway diesel fuel shipped by pipeline that must be downgraded to a lower value product must be downgraded to off highway diesel fuel. Therefore, the additional cost of downgrading the current volume of highway diesel fuel that must be downgraded will be based on the difference in the cost of producing 15 ppm highway diesel fuel and off highway diesel fuel (6.5 cents per gallon) compared to the current difference in cost between 500 ppm highway diesel fuel and off highway

[v] See section V.C.3.k. regarding the extent that we expect the distribution system will carry 500 ppm highway diesel fuel during the initial years of our program when the temporary compliance option is available.

[w] See table V.C-20 and the associated text in section V.C.2. for a discussion on the difference in the cost of producing 15 ppm highway diesel fuel and that of producing 500 ppm highway diesel fuel.

diesel fuel (2.2 cents per gallon).[x] Our estimate of the additional cost (0.09 cents per gallon of highway diesel fuel supplied) after our sulfur program is fully effective was calculated by multiplying the 4.3 cents per gallon price differential by the fraction of the highway diesel pool that is currently downgraded to a lower value product (0.022).[y] Costs during the initial years of our program are reduced by 20 percent at (to 0.08 cents per gallon of highway diesel fuel supplied) because on average only 80 percent of the highway diesel fuel pool will be 15 ppm fuel during the initial years of our program when the temporary compliance option is available.[z]

e. Increased Cost of Downgrading the Interface Between Pipeline Shipments of Highway Diesel Fuel and Jet Fuel or Kerosene

Please refer to section IV.D.2.a in this RIA for a more thorough discussion of the change that will need to take place in the handling practices for the interface volumes between adjacent pipeline shipments of highway diesel fuel and jet fuel or kerosene. This section addresses our estimation of the costs of this change.

Expressed in terms of the volume of highway diesel fuel supplied, we estimate the increased cost of handling these interface volumes will be 0.07 cents per gallon after our becomes sulfur program fully effective. This cost arises from the fact that all of the interface volume between adjacent batches of highway diesel fuel and jet fuel or kerosene will need to be downgraded to off highway diesel fuel once our program becomes fully effective. During the initial years of our program, we estimate that the cost will be 0.03 cents per gallon. The costs is somewhat less during the initial years of our program because there is some opportunity to make the downgrade to 500 ppm highway diesel fuel rather than off highway diesel fuel. Additional storage tanks will be needed at those terminals that currently do not handle off highway diesel fuel. The cost of these tanks has been fully accounted for in the calculation of costs during the initial years of our program as discussed below (0.009 cents per gallon).

Since a clean interface cut is already made between batches of highway diesel fuel and jet fuel or kerosene, there will be no increase in the volume of product downgraded under our program. However, the entire interface volume between highway diesel fuel and jet fuel or kerosene will need to be directed into a storage tank containing off highway diesel fuel when the 15 ppm cap on the sulfur content of highway diesel fuel is implemented. The current practice is to cut all of the interface volume associated with adjacent batches of highway diesel fuel and jet

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[x] See table V.C-20 and the associated text in section V.C.2. for a discussion on the relative cost of producing these different types of diesel fuel.

[y] See section IV.D.2. for a discussion in our estimation of the current downgrade volume.

[z] See section V.C.3.k. for a discussion on the relative volumes of 15 ppm and 500 ppm highway diesel fuel during the initial years of our sulfur program.

fuel or kerosene into the batch of highway diesel fuel. When our sulfur program is fully effective, the increased cost associated with this downgrade will be based on the difference in cost between 500 ppm highway diesel fuel and off highway diesel fuel (2.2 cents per gallon). This is because the downgrade will be made to off highway diesel fuel rather than 500 ppm highway diesel fuel as it is today.

To account for the fact that not all batches of highway diesel fuel are shipped by pipeline adjacent to a batch of jet fuel, 2.2 cents per gallon was multiplied by the ratio of the volume of jet fuel and kerosene supplied to the volume of highway diesel fuel supplied (0.72). For the purpose of this calculation, we assumed that 72 percent of the highway diesel fuel batches shipped by pipeline abut a shipment of jet fuel or kerosene. We derived the ratio of the volume of jet fuel and kerosene supplied to the volume of highway diesel fuel supplied using the following data from the Energy Information Administration (EIA):[79]

- Jet Fuel and kerosene supplied in 1999 = 637,123,000 barrels = 26,759,166,000 gallons
- 500 ppm diesel supplied in 1999 = 887,355,000 barrels = 37,268,910,000 gallons
- (jet fuel + kerosene) / 500 ppm diesel = 0.72

To arrive at our estimate of the additional cost of the downgrade associated with batches of highway diesel fuel that abut batches of jet fuel or kerosene during shipment by pipeline when our program is fully effective, we multiplied the volume of the downgrade by the difference between the cost of 500 ppm highway diesel fuel and off highway diesel fuel (2.2 cents per gallon).

During the initial years of our program, 40 percent of pipeline systems will carry both 500 ppm and 15 ppm highway diesel fuel. In such systems the downgrade can continue to be made to 500 ppm diesel fuel rather than off highway diesel fuel. Therefore, there will be no additional cost associated with this downgrade. Consequently, the additional cost of the downgrade is reduced by 40 percent during the initial years of our sulfur program (0.07 x 40 percent = 0.03 cents per gallon).

Following is a discussion of how we arrived at our estimate of 0.009 cents per gallon of highway diesel fuel produced for the storage tanks that will be needed to accommodate the interface between pipeline shipments of highway diesel fuel and jet fuel/kerosene at terminals that do not already have a storage tank that contains off highway diesel fuel. We estimated that approximately 60 percent of terminals will not have such a tank (588 terminals). At such terminals, we estimate that a single 4,000 gallon above ground tank will be installed at a cost of $20,000 per tank. The total tank cost will be $11,760,000. This cost was amortized (at 7 percent per annum) over the initial years of the sulfur program to arrive at our estimate of 0.009 cents per gallon of highway diesel fuel supplied. We used our estimate of the total volume of highway diesel fuel supplied in 2006[aa] (39,504,000,000 gallons) to arrive at this per gallon estimate.

f. Cost of Additional Quality Control Testing at Petroleum Terminals

The additional quality control testing at the terminal level needed to ensure compliance with the 15 ppm sulfur cap would be the same during the initial years of our program as after the requirements are fully implemented. We estimate the cost of such additional quality assurance measures will be $100 for each batch. This estimate includes the cost of sampling and testing each batch for its sulfur content. A typical pipeline batch of highway diesel fuel shipped by pipeline is 100,000 barrels. By dividing the estimated cost per batch by the average size of a batch, we arrived at an estimate of 0.002 cents per gallon of highway diesel fuel supplied for the cost of the additional quality control measures needed at terminal facilities.

g. Cost of Downgrading the Additional Pipeline Interface Volumes Associated with the Shipment of Highway Diesel Fuel that Meets a 500 ppm Sulfur Cap During the Initial Years of Our Sulfur Program

The presence of two grades of highway diesel fuel (500 ppm and 15 ppm) during the initial years of our program will cause the generation of additional pipeline interface volumes and associated downgrade costs. This is because there will be more batches of highway diesel fuel shipped in the 40 percent of pipelines that carry both grades of highway diesel fuel.[bb] We estimate the additional cost during the initial years of our program will be 0.004 cents per gallon of the total volume of highway diesel fuel supplied (500 and 15 ppm sulfur cap fuel).

We arrived at this estimate by multiplying the following factors:

- The volume of the downgrade associated with pipeline shipments of 500 ppm highway diesel fuel (2.2 percent)[cc]

[aa] The estimate of highway diesel fuel supplied in 2006 was derived by growing the estimate of highway diesel fuel supply in 1999 from the Energy Information Administration (EIA) Petroleum Supply Annual, June 2000, by 1.5 percent each year. See docket item IV-A-07 for a discussion of our use of the 1.5 percent growth factor.

[bb] See section V.C.3.k. in this RIA regarding the extent that we expect the distribution system will carry 500 ppm highway diesel fuel during the period when the temporary compliance option is available.

[cc] See section IV.D.2. in this RIA for a discussion of our estimate of the volume downgraded.

- The fraction of the highway diesel pool we expect to be 500 ppm fuel (approximately 20 percent during the initial years of our program)[dd]

- The fraction of the pipeline system that will carry 500 ppm fuel (40 percent)[ee]

- The cost of the downgrade (2.2 cents per gallon)

h. Cost of Optimizing the Distribution System to Distribute 15 ppm Highway Diesel Fuel

As more fully discussed in section IV.D, we expect that the distribution industry will conduct various tests to evaluate potential sources of contamination prior to the implementation of our sulfur control program. During this evaluation, we anticipate that minor procedural and equipment changes may be identified in addition to those which we have specifically assigned a cost to. Such additional changes may include:

- Testing the system to evaluate sources of contamination
- Valve replacements
- Moving pipeline batch monitoring systems upstream and/or speeding the means to make batch changes
- Education programs for tank truck, tank wagon, and rail car operators on practices to limit contamination

We believe that the costs associated with such optimization practices will be relatively minor and readily accommodated by the distribution industry. Such costs will only occur once and the associated situations will be the exception rather than the rule. Since commenters did not provide an estimate of the frequency when such instances might arise, it is difficult to estimate a cost. Based on engineering judgement, having reviewed the information in the comments and the potential cost for a range of potential activities, we estimate that the fuel distribution industry will invest another $100,000,000 to optimize its ability to limit sulfur contamination in addition to the costs that we have specifically identified (e.g. downgrade, additional tanks). We estimate that this investment will be made almost entirely by pipeline and terminal operators. We amortized this cost at 7 percent per annum over the period from the program's start-up in 2006 through 2020. During the initial years of our program, this results in a cost of 0.027 cents per

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[dd] For the purpose of this calculation, we used 20 percent for the entire 4 year period when the temporary compliance option is available. See section V.C.3.k. in this RIA for a discussion of how the relative volumes of 15 ppm and 500 ppm highway diesel fuel vary over the period when the temporary compliance program is available. For example, during the first year of our sulfur program, we estimate that 22 percent of highway diesel fuel will meet a 500 ppm sulfur cap.

[ee] See section V.C.3.k. in this RIA regarding the extent that we expect the distribution system will carry 500 ppm highway diesel fuel during the period when the temporary compliance option is available.

gallon of highway diesel fuel supplied. When our program is fully effective, we estimate the cost at 0.025 cents be gallon through the year 2020.

i. Additional Measures by Tank Truck, Tank Wagon, and Rail Car Operators to Limit Contamination

As discussed in the section on the feasibility of distributing 15 ppm highway diesel fuel (section IV.D.), we continue to believe that there will only be negligible costs to tank truck, tank wagon, and rail car operators associated with limiting contamination during the distribution of 15 ppm highway diesel fuel. Given the such potential cost would be very small, we believe they are sufficiently well accounted within the costs we have attributed to the optimization of the distribution system to limit contamination (V.C.3.h.).

j. Potential Costs Associated with the Voluntary Phase Out of High Sulfur Diesel Additives

As discussed in the section on the feasibility of distributing 15 ppm diesel fuel (section IV.D.), we believe that the allowance for the continued use of diesel fuel additives which exceed 15 ppm in sulfur content will prevent any significant cost impacts from our program related to the use of diesel fuel additives.

k. Costs During the Initial Years of Our Program Due to the Need for Additional Storage Tanks to Handle Two Grades of Highway Diesel Fuel

The most substantial additional costs associated with the temporary compliance option are due to the need to handle an additional grade of highway diesel fuel in the distribution system. During the initial years of our program when the temporary compliance option is available, we expect that the production of 500 ppm sulfur fuel will be much less than that of 15 ppm fuel. At the same time, most of the diesel vehicle fleet can burn 500 ppm fuel during this period. Because of its greater volume and the need to distribute it everywhere in the country, we expect that essentially all pipelines and terminals will handle 15 ppm fuel. In contrast, distribution of 500 ppm fuel will concentrate on those areas nearest the refineries producing that fuel, plus a few major pipelines serving major refining areas.

Regarding distribution to the final user, we expect that nearly all truck stops in areas where 500 ppm fuel is available will invest in piping and tankage to handle a second fuel. Because of the significant expense involved in adding a second tank, in these areas, we expect service stations will only carry one fuel or the other, as market demands dictate. Likewise, we expect that centrally fueled fleets and card locks will only handle 15 ppm fuel. Under this scenario, sales of 500 ppm fuel are limited to only those vehicles which refuel at truck stops and service stations. This is somewhat conservative since some centrally fueled fleets may have the flexibility to inexpensively handle two fuels. Likewise, some card locks in a given area may be able to carry 15 ppm fuel and others 500 ppm fuel and still serve their clients at little extra cost. Still, given the above assumptions, we project that the 500 ppm fuel will have to be distributed to areas representing about 50% of the national diesel fuel demand. Also, as the fleet turns over to 2007 and later vehicles, the amount of 500 ppm fuel produced under the temporary compliance option will gradually decrease from roughly 22 percent in 2007 to about 16 percent in 2010.

The tankage cost at refineries, terminals, pipelines and bulk plants handling both fuels is estimated to be $0.81 billion. We estimate that 11 refineries will produce both fuels. These are refineries with hydrocrackers which are not projected to invest in new hydrotreating equipment in 2006. Thus, these refineries will produce a small amount of 15 ppm fuel from its hydrocrackate and 500 ppm fuel from the rest of its current highway diesel fuel blendstocks. At $1 million per tank, this totals to $11 million.

We estimate that there are 853 terminals which currently carry highway diesel fuel, excluding tanks at refineries. We assume that 40% of these terminals would build a new tank in order to distribute two fuels to 50% of the U.S. market and keep tank truck driving distances at current levels. We estimate only 40% of these terminals would need an extra tank, rather than 50%, because 56 refineries will be producing the 500 ppm fuel and will distribute this fuel directly to their local areas. At a cost of $1 million per tank, terminal tankage will cost a total of $340 million.

Likewise, we estimate that there are 9200 bulk plants which currently carry highway diesel fuel, excluding tanks at refineries. We estimate that a new tank at these facilities would cost $125,000. Again assuming that 40% of these bulk plants would build a new tank in order to distribute two fuels to 50% of the U.S. market, this tankage would cost a total of $460 million.

Finally, we estimate that 50% of the nation's truck stops would also build a new tank or otherwise provide for a second fuel. There are 4800 truck stops currently operating in the U.S.[80] The National Association of Truck Stop Operators (NATSO) surveyed their members regarding the expected cost to handle a second grade of highway diesel fuel.[81] We weighted the responses to this survey to arrive at our estimate that it would cost $100,000 per truck stop on average to handle a second fuel. This totals to $240 million. Thus, the total cost for new tankage at all of these facilities is $1.05 billion.

We then amortized these one time costs over the 15 ppm fuel produced during the initial years of our program at 7 percent per annum. We estimated that, with the small refiner option, the total percentage of 15 ppm fuel produced during the first year of our program would be 78% (though it could be as low as 75% if all small refiners chose to delay production of 15 ppm fuel). This continued through 2008. However, in 2008, the limitation of distributing 500 ppm fuel only through truck stops and service stations and only in 70% of the U.S. diesel fuel market, as well as the turnover of the vehicle fleet to 2007 and later vehicles, began to be controlling. We estimate that truck stops and service stations distribute 61% of all highway diesel fuel in the U.S. We assumed that these outlets sold 15 ppm and 500 ppm in proportion to the in-use vehicle fleet (i.e., 2007 and later vehicles used 15 ppm fuel and earlier vehicles used 500 ppm fuel). Thus, in 2009 and 2010, we estimated that 81%, and 83.5% of all highway diesel fuel would meet the 15 ppm standard. The last figure was assumed to apply through mid- 2010, based on the use of banked credits from earlier periods. Amortizing the tankage cost over the 15 ppm fuel produced over this period, the cost per gallon is 0.9 cents.

4. What is the Cost of Lubricity Additives?

Adoption of the cap on diesel fuel sulfur could result in a decrease in the lubricity of highway diesel fuel produced by some refiners. This could necessitate the use of additional quantities of lubricity-improver additives to maintain in-use lubricity performance (see Section IV.C.).

A study by MathPro Inc. (MathPro)[82] in 1999, sponsored by the Engine Manufacturers Association to estimate the costs of diesel fuel desulfurization under sulfur standards that we were likely to require, received estimates from lubricity additive suppliers indicating that the costs of lubricity additives would average 0.1 to 0.5 cents per gallon. The lower the sulfur standard, typically the higher the lubricity cost. We independently contacted some producers and distributors of lubricity additives, which also provided estimated average costs in the range of 0.1 to 0.5 cents per gallon for large volumes of treated fuel. Again, the estimates varied depending on the sulfur standard, ranging from a cap of 5 to 50 ppm. MathPro utilized vendor cost estimates to derive lubricity additive cost estimates under a number of possible diesel fuel sulfur control scenarios. These estimates ranged from 0.1 to 0.3 cents per gallon depending on the control case (see Table V.C-28).

Table V.C-28. MathPro Lubricity Additive Cost Estimates

Sulfur Control Case (avg. sulfur standard)		*Estimated Lubricity Additive Cost (cents/gallon)*
Highway Diesel	*Off Highway Diesel*	
150 ppm	uncontrolled (3500 ppm)	0.1
150 ppm	150 ppm	0.1
50 ppm	50 ppm	0.1
20 ppm	350 ppm	0.1
20 ppm	20 ppm	0.2
2 ppm	350 ppm	0.2
2 ppm	2 ppm	0.3

Unfortunately, MathPro did not provide costs for a case consistent with the 15 ppm sulfur standard. In addition, MathPro cases included control of off highway diesel fuel. Nevertheless, the cases evaluated in the MathPro study can be used to approximate the cost of lubricity additives under the 15 ppm cap for highway diesel fuel. Of the cases evaluated by MathPro, we believe its highway/off-highway 20 ppm average scenario most closely matches our highway-only 15 ppm cap case with respect to the potential impact on lubricity additive cost. While our projected refinery average sulfur level of 7 ppm is closer to 2 ppm than 20 ppm, we believe that Mathpro's 2 ppm case, which includes the desulfurization of both highway and non-highway diesel fuel to this level, is much more severe with respect to lubricity changes than a 7 ppm level for highway diesel fuel only. Thus, using the vendor-supplied cost estimates, coupled with the estimates for the various scenarios evaluated by MathPro, we estimate that the cost of lubricity additives under the 15 ppm sulfur cap would be in the range of 0.2 cents per gallon.

In considering the comments, we have found no basis in today's action to use a different average cost estimate to treat low sulfur diesel fuel for lubricity than that which was used in the proposal. Of the two comments we received on this issue, one supported our cost estimate of 0.2 cents per gallon. The other was submitted by DOD, which indicated it has experienced lubricity additive costs from one to five cents per gallon. We believe that DOD's experience with lubricity properties and lubricity additives is not typical of commercial users for several reasons. First, DOD commented that, due to harsher operating conditions, engines used in DOD vehicles, especially tactical vehicles, are more vulnerable to lubricity problems than the same engines operated in commercial vehicles. Also, the fuel DOD uses at its facilities is purchased under contract usually for a year or longer. Thus, the DOD fuel generally is from a single supplier and does not have the beneficial effect of blending or mixing different batches of fuel or fuel from different suppliers, such as that which occurs in the commercial market. As discussed in Section IV, blending or mixing different batches of diesel fuel minimizes the effect of isolated poor lubricity fuels. Consequently, DOD might be taking more aggressive action in responding to lubricity concerns than might be needed for commercial applications. Second, DOD is using an additive that is primarily a corrosion inhibitor. It is our understanding that DOD found that the additive it uses to address a corrosion property in the fuel is also effective at improving lubricity, and subsequently has been using that additive to also address its lubricity concerns. If DOD were able to ignore its corrosion property concerns, it is possible that a formulation specifically for lubricity might cost less, or that its treat rate could be less, than that of the corrosion inhibitor formulation and treat rate it currently uses. Finally and most importantly, we believe that DOD's experience is more reflective of the prices that might be experienced with specialty additives supplied in relatively small quantities. With the 15 ppm standard, most, if not all, of the nation's highway diesel fuel may need to be treated for lubricity. Economies of scale associated with bulk production as opposed to more specialty products will drive down the unit cost of lubricity additives considerably.

5. Benefits of 15 ppm Diesel Fuel for the New and Existing Diesel Fleet

In addition to its role as a technology enabler, low sulfur diesel fuel gives benefits in the form of reduced sulfur induced corrosion of vehicle components and slower acidification of engine lubricating oil, leading to longer maintenance intervals and lower maintenance costs. These benefits will apply to new vehicles and to the existing heavy-duty vehicle fleet beginning in 2006 when the fuel is introduced. These benefits can offer significant cost savings to the vehicle owner without the need for purchasing any new technologies. These benefits are estimated here for new vehicles and for vehicles in the existing fleet (pre-2007 fleet).

The individual components of the engine system which might be expected to realize benefits from the use of low sulfur diesel fuel are summarized in Table V.C-29 and are described in more detail in the following sections.

Table V.C-29. Components Potentially Affected by Lower Sulfur Levels in Diesel Fuel

Affected Components	*Affect of Lower Sulfur*	*Potential Impact on Engine System*
Piston Rings	Reduce corrosion wear	Extended engine life and less frequent rebuilds
Cylinder Liners	Reduce corrosion wear	Extended engine life and less frequent rebuilds
Oil Quality	Reduce deposits and less need for alkaline additives	Reduce wear on piston ring and cylinder liner and less frequent oil changes
Exhaust System (tailpipe)	Reduces corrosion wear	Less frequent part replacement
EGR	Reduces corrosion wear	Less frequent part replacement

The actual value of these benefits over the life of the vehicle will depend upon the length of time that the vehicle operates on low-sulfur diesel fuel. For a vehicle near the end of its life in 2007 the benefits will be quite small. However for vehicles produced in the years immediately preceding the introduction of low-sulfur fuel the savings will be substantial. These savings are estimated here for new and existing diesel vehicles beginning in 2006 and continuing through 2035. The costs are expressed in terms of dollars saved per mile or in terms of dollars saved in a particular year (for rebuild savings).

These savings, due to the use of low sulfur diesel fuel, can also be expressed in terms of a savings in cents per gallon of low sulfur diesel fuel. Taking the savings detailed in each of the subsections below and expressing them in terms of cents per gallon gives an average savings of approximately 1.4 cents/gallon for light heavy-duty diesels, 1 cent/gallon for medium heavy-duty diesel engines and 0.7 cents/gallon for heavy heavy-duty diesel engines. The average savings estimated across all weight classes is therefore approximately one cent per gallon. While there may be uncertainty regarding the magnitude of this effect, this estimate may in fact be a conservative estimate of the savings as there are likely to be other benefits not accounted for in this analysis.

a. Methodology

Under contract from EPA, ICF Consulting provided surveys to nine engine manufacturers seeking their input on expectations for cost savings which might be enabled through the use of low sulfur diesel fuel and seeking their estimations of the cost and types of emission control technologies which might be applied with low sulfur diesel fuel. In general, the respondents to the survey gave qualitative rather than precise quantitative estimates of the benefits of low sulfur diesel fuel. While all respondents agreed that savings will occur, their estimates were often based on rough approximations of future engine characteristics. Based on responses to this survey, EPA estimated cost savings to the current and future fleets through the use of low sulfur diesel fuel.[83]

For new vehicles we have estimated the value of these benefits in terms of a net present value in the year of vehicle sale. This allows for us to calculate a per vehicle cost of control and a per vehicle cost effectiveness for the program. In order to calculate aggregate benefits for the new fleet and for the existing fleet this approach is not appropriate as each vehicle in the fleet will accrue benefits at different rates over different periods, depending upon their year of introduction and their technology mix. Additionally, it is more telling to describe the cost savings as an aggregate benefit to the fleet, just as fuel costs are shown as an aggregate cost to the fleet. Therefore, where possible, we have estimated the benefits of low sulfur diesel fuel to the new and existing heavy-duty vehicle fleets in terms of dollars per vehicle mile traveled. In the one case, where the savings are related to a discrete event (engine rebuilds), we have applied a single savings estimated to a specific fraction of the existing fleet as described below. These savings are then accumulated over the entire pre-2007 heavy-duty fleet and over the new fleet of vehicles introduced in 2007 in each year from 2006 through 2035, and are reported as an aggregate savings.

If refiners avail themselves of the temporary compliance option and hardship provisions available to them in the early years of the program, some fraction of the existing fleet would continue to operate on current 500 ppm sulfur diesel fuel. In order to account for this possibility in our analysis, we have assumed that 22 percent of the total fuel consumption during the transition period will be today’s 500 ppm sulfur fuel. The analysis also assumes that the new vehicles will be fueled exclusively on the new low sulfur diesel fuel and that only the fraction of the existing fleet operating on the remaining fraction of the low sulfur diesel fuel will realize a benefit.

b. Extended Oil Change Intervals

Sulfur in diesel fuel leads to acidification of engine lubricating oils, directly causing increased corrosion and increased rates of engine wear. Lubricating oils use alkaline additives to neutralize the acidifying nature of sulfur compounds formed in the engine from sulfur in diesel fuel. These basic compounds are consumed over time leading to a loss of pH control in the oil. Oil change intervals are often determined based upon the period of time required for the basic compounds in the oil to be consumed. The use of low sulfur diesel fuel will decrease this rate of oil acidification leading to extended periods between required oil change maintenance intervals. While it is difficult to quantify a precise benefit, most observers agree that use of very low sulfur fuel will probably extend oil drain intervals. Based on information from some engine manufacturers and others, we have assumed that engine oil change intervals will be extended by ten percent due to the use of low sulfur diesel fuel. Based on this benefit the per mile savings can be estimated as shown in Table V.C-30.

Table V.C-30. Cost Savings to the Existing Fleet from Extend Oil Change Intervals Made Possible by Low Sulfur Diesel Fuel

	Units	*LHD*	*MHD*	*HHD*
Base Oil Change Interval*	miles	8,000	11,000	18,000
Low Sulfur Oil Change Interval*	miles	8,800	12,100	19,800
Cost Per Oil Change*	$	$100	$150	$200
Base Oil Change Cost per Mile	$/mile	$0.0125	$0.0136	$0.0111
Low Sulfur Oil Change Cost per Mile	$/mile	$0.0114	$0.0124	$0.0101
Oil Change Cost Difference per Mile	$/mile	$0.0011	$0.0012	$0.0010
Average Fuel Economy	miles/gallon	11.8	8.0	5.9
Cost Savings Per Gallon Fuel	$/gallon	$0.0134	$0.0099	$0.0060

*Oil change intervals for vehicles operating on low sulfur diesel fuel are assumed to increase by ten percent, average oil change intervals, and costs for oil changes from ICF Consulting report.[84]

For vehicles produced after the introduction of the low sulfur diesel fuel in 2006 these benefits can also be expressed in terms of an average cost savings over the life of the vehicle. The cost savings are estimated using typical mileage accumulation rates given in each year of a vehicles life from our inventory emissions model and the typical oil change interval and costs described above. These savings are then expressed in terms of a net present value in the year of the vehicle sale. The savings realized for extended oil change intervals on vehicles fueled exclusively on low sulfur diesel fuel are estimated to be $153 for light heavy-duty vehicles, $249 for medium heavy-duty vehicles and $559 for heavy heavy-duty vehicles.

c. Extended EGR System Life

In the RIA for the 2004 heavy-duty engine standards, we estimated that exhaust gas recirculation (EGR) systems, particularly EGR valves, will require service or replacement as part of the engine rebuild process. This estimate was based primarily upon our concern for the detrimental effects of sulfur in diesel fuel on EGR system durability. The use of low sulfur diesel fuel mitigates this concern and leads us to conclude that the EGR valve used in these systems can be expected to last the life of the engine. Eliminating the replacement of the EGR valve on heavy heavy-duty diesel engines represents a cost savings to vehicles built with EGR systems of $115 in the year of the engine rebuild. These savings are only estimated for vehicles built after 2004, because vehicles built prior to that date will have operated primarily on current high sulfur diesel fuel. Savings for light and medium heavy duty vehicles are not estimated because engines in these vehicle classes are less likely to be rebuilt. The analysis also assumes that vehicles with EGR systems will be operated primarily on the new low sulfur diesel fuel when it becomes available in 2006. Although some fraction of the existing fleet may be operating on high sulfur diesel fuel during that period, we believe that owners of vehicles with EGR systems will preferentially choose the low sulfur diesel fuel for the maintenance benefits it provides. The aggregate savings for vehicles sold in 2004-2006 and rebuilt in 2009-2011 are shown in Table V.C-31. The aggregate savings for vehicles built beginning in 2007 and rebuilt beginning in 2012 are presented in Table V.C-32. These savings can also be expressed in terms of a net present value in the year of vehicle sale of $51.

Table V.C-31. Cost Savings to the Existing Fleet for Reduced EGR System Replacement Made Possible by Low Sulfur Diesel Fuel*

Year Rebuilt (7th year of life)	*Model Year*	*Calendar Yr Sales*	*Surviving in Year 7*	*Number Rebuilt*	*Aggregate Savings*
2010	2004	259,600	185,874	176,580	$20,306,691
2011	2005	264,000	189,024	179,573	$20,650,872
2012	2006	268,400	192,174	182,566	$20,995,053

* $115 per vehicle cost savings if the EGR valve is not replaced when the engine rebuild occurs. The table assumes that only Heavy Heavy-Duty engines are rebuilt, that 95 percent of vehicles reaching 560,000 miles are rebuilt, and that 72 percent of heavy heavy-duty vehicles reach 560,000 miles (on average in year 7 of their life).

Table V.C-32. Cost Savings to the New Fleet (2007 and later) for Reduced EGR System Replacement Made Possible by Low Sulfur Diesel Fuel*

Year Rebuilt (7th year of life)	*Model Year*	*Calendar Yr Sales*	*Surviving in Year 7*	*Number Rebuilt*	*Aggregate Savings*
2013	2007	272,800	195,325	185,559	$21,339,234
2014	2008	277,200	198,475	188,551	$21,683,416
2015	2009	281,600	201,625	191,543	$22,027,598
2016	2010	286,000	204,775	194,535	$22,371,780
2017	2011	290,400	207,925	197,527	$22,715,962
2018	2012	294,800	211,075	200,519	$23,060,144
2019	2013	299,200	214,225	203,511	$23,404,326
2020	2014	303,600	217,375	206,503	$23,748,508
2021	2015	308,000	220,525	209,495	$24,092,690
2022	2016	312,400	223,675	212,487	$24,436,872
2023	2017	316,800	226,825	215,479	$24,781,054
2024	2018	321,200	229,975	218,471	$25,125,236
2025	2019	325,600	233,125	221,463	$25,469,418
2026	2020	330,000	236,275	224,455	$25,813,600
2027	2021	334,400	239,425	227,447	$26,157,782
2028	2022	338,800	242,575	230,439	$26,501,964
2029	2023	343,200	245,725	233,431	$26,846,146
2030	2024	347,600	248,875	236,423	$27,190,328
2031	2025	352,000	252,025	239,415	$27,534,510
2032	2026	356,400	255,175	242,407	$27,878,692
2033	2027	360,800	258,325	245,399	$28,222,874
2034	2028	365,200	261,475	248,391	$28,567,056
2035	2029	369,600	264,625	251,383	$28,911,238

* $115 per vehicle cost savings if the EGR valve is not replaced when the engine rebuild occurs. The table assumes that only Heavy Heavy-Duty engines are rebuilt, that 95 percent of vehicles reaching 560,000 miles are rebuilt, and that 72 percent of heavy heavy-duty vehicles reach 560,000 miles (on average in year 7 of their life).

d. Extended Exhaust System Life

Exhaust system components, specifically exhaust pipes and mufflers, typically fail due to perforations caused by corrosion of the pipe walls. Corrosion rates are increased by sulfuric acid present in diesel exhaust which can condense on the walls of the exhaust system. This sulfuric acid is a by-product of combustion with sulfur in diesel fuel. When sulfur is removed from diesel fuel the amount of sulfuric acid formed decreases proportionally, thereby reducing corrosion rates due to sulfuric acid in diesel exhaust. The survey respondents acknowledged that this may be a cost savings to the consumer, but were not able to quantify the savings or determine the percent extended life. One manufacturer characterized the savings as marginal. Based on this information, we have assumed that the reduction in sulfuric acid induced corrosion may extend exhaust system component life by five percent, leading to a cost savings to the existing vehicle fleet. Based on this estimate and estimates of average exhaust system life and average exhaust system replacement costs, a per mile estimate of this cost savings can be determined as shown in Table V.C-33. We have not applied this savings to estimates for the new vehicle fleet because we do not anticipate the use of a muffler on vehicles equipped with diesel PM filters.

Table V.C-33. Cost Savings to the Existing Fleet from Extend Exhaust System Replacement Intervals Made Possible by Low Sulfur Diesel Fuel

	Units	*LHD*	*MHD*	*HHD*
Exhaust System Change Interval	miles	110,000	147,000	334,000
Low Sulfur Exhaust Change Interval*	miles	115,500	154,350	350,700
Exhaust Replacement Cost	$	$275	$379	$491
Base Cost per Mile	$/mile	$0.0025	$0.0026	$0.0015
Low Sulfur Cost per Mile	$/mile	$0.0024	$0.0025	$0.0014
Cost Difference Per Mile	$/mile	$0.0001	$0.0001	$0.0001
Average Fuel Economy	miles/gallon	11.8	8.0	5.9
Cost Savings Per Gallon Fuel	$/gallon	$0.0014	$0.0010	$0.0004

* Exhaust system life for vehicles operating on low sulfur diesel fuel are expected to increase by 5 percent.[85]

e. Extended Rebuild Intervals and Engine Life

Engine rebuilds and replacements often occur when excessive wear of the engine cylinder kit (primarily the cylinder liner and engine piston rings) causes high oil consumption rates, decreased engine performance and increased fuel consumption rates. Wear rates of these components can increase due to corrosion caused by sulfur in diesel fuel. Therefore, in as much as low sulfur diesel fuel can be expected to decrease corrosion, it can also be expected to similarly decrease component wear rates, thereby leading to increased component life. Extending engine life or the time between engine rebuilds, can lead to a direct savings to the consumer.

Estimating an average extension of engine life is difficult due to the many factors that affect engine wear and overall engine life. We believe the strong influence of sulfur in diesel fuel on engine wear could lead to estimates of about five percent. However, because engine wear rates are also linked to oil change intervals it may not be appropriate to claim full credit for both extended oil change intervals and extended engine rebuild intervals. Therefore, in order to be conservative in our estimates, we have not included these cost savings in our estimates of aggregate cost savings realized through the use of low sulfur diesel fuel.

f. Aggregate Cost Savings for the New and Existing Diesel Fleet Realized from Low Sulfur Diesel Fuel

By applying the cost savings described in the preceding sections to the predicted vehicle miles traveled for each class of heavy-duty vehicle in the inventory calculation model described in chapter 2 of this RIA, an estimated aggregate savings can be calculated. These savings are shown for the fraction of the existing fleet (pre-2007 vehicles) operating on the new low sulfur diesel fuel in Table V.C-34 beginning with the savings realized in 2006 from the introduction of low sulfur diesel fuel in that year. As vehicles in the pre-2007 fleet are retired from service these cost savings decrease as reflected in the table.

Aggregate savings for vehicles introduced beginning in 2007 are estimated in the same manner except that they are assumed to always be operated on the required low sulfur diesel fuel and are presented in Table V.C-35. As the number of new vehicles in the fleet increases the total savings realized through the use of low sulfur diesel fuel increases in proportion as seen in the table.

Table V.C-34. Aggregate Savings to the Existing Fleet (pre-2007 fleet) Made Possible by Low Sulfur Diesel Fuel

Calendar Year	*Aggregate Savings*
2006	$80,431,146
2007	$220,884,072
2008	$182,897,940
2009	$149,160,147
2010	$150,798,213
2011	$134,706,583
2012	$120,588,873
2013	$86,874,251
2014	$75,690,690
2015	$65,859,406
2016	$63,293,317
2017	$73,979,411
2018	$64,024,039
2019	$55,275,661
2020	$47,592,312
2021	$40,856,134
2022	$34,971,949
2023	$29,858,909
2024	$25,419,320
2025	$21,528,956
2026	$18,117,665
2027	$15,124,047
2028	$12,494,644
2029	$10,182,634
2030	$8,147,249
2031	$6,307,402
2032	$4,685,085
2033	$3,334,379
2034	$2,061,983
2035	$949,181

Table V.C-35. Aggregate Savings for the New Fleet (2007 and later) Made Possible by Low Sulfur Diesel Fuel

Calendar Year	*Aggregate Savings*
2006	$0
2007	$24,971,224
2008	$66,505,419
2009	$104,161,427
2010	$138,377,022
2011	$169,546,107
2012	$198,021,885
2013	$245,459,554
2014	$269,806,304
2015	$292,307,844
2016	$313,186,610
2017	$332,638,971
2018	$350,838,377
2019	$367,935,864
2020	$384,061,052
2021	$399,321,575
2022	$413,804,401
2023	$427,583,405
2024	$440,747,742
2025	$453,410,634
2026	$465,636,121
2027	$477,480,251
2028	$488,991,818
2029	$500,213,568
2030	$511,182,712
2031	$521,973,234
2032	$532,565,116
2033	$542,908,991
2034	$553,181,391
2035	$563,308,011

6. Per-Engine Life-Cycle Fuel Costs

The additional cost of diesel fuel meeting our 15 ppm cap is encountered by the average engine owner each time the fuel tank is refilled. The impacts of the diesel sulfur standard on the average engine owner can therefore be calculated as the increased fuel costs in cents per gallon, multiplied by the total number of gallons used by an engine over a particular timeframe. Thus we have calculated the in-use impact of our diesel sulfur standard on a per-engine basis for both a single year and for an engine's entire lifetime.

Since we have introduced a temporary compliance option and small refiner hardship provisions for the diesel sulfur standard that will apply in the initial years, both 15 ppm highway fuel and 500 ppm highway fuel will be present in the distribution system at the same time during these years. As discussed in Section V.C above, there are both refinery cost savings and distribution system costs that occur as a result of these provisions. It is appropriate to consider these costs and savings as applying to the entire highway diesel pool. In order for refiners to continue producing 500 ppm fuel, we anticipate that they will have to purchase credits from refiners producing 15 ppm fuel, in essence rasing the cost of producing 500 ppm fuel and lowering the cost of producing 15 ppm fuel. Furthermore the distribution system costs are likely to be recouped by the industry across both grades of highway diesel fuel. As a result, we have concluded that the fuel costs associated with the program we are finalizing today should be assigned equally to all gallons of highway diesel fuel, whether 15 ppm or 500 ppm sulfur fuel.

The total cost of 15 ppm diesel fuel is the sum of refinery desulfurization costs, addition of a lubricity additive, and increases in distribution costs. Refinery desulfurization and distribution costs are discussed earlier in this Chapter, and average 3.3 ¢/gal and 1.1 ¢/gal respectively during the initial years of the program. Lubricity additives are discussed in Section V.C.4, and average approximately 0.2 ¢/gal. Thus we estimate the total cost of diesel fuel meeting our 15 ppm cap to be 4.5 ¢/gal during the initial years of the program. This cost will increase to 5.0 ¢/gal after 2010.

In a single year, the average in-use heavy-duty engine travels approximately 30,000 miles[ff], though the mileage of any given engine varies by usage, age, and other factors. Applying the average heavy-duty fuel economy, the cost for 15 ppm diesel fuel of 4.5 ¢/gal leads us to a per-engine estimate of approximately $187. This is the additional cost that the average engine owner will incur for fuel in the first year of our program, if the full social costs of meeting our standards are passed onto consumers. However, fuel prices may be higher or lower depending on market conditions. The costs for different engine classes will vary, of course, based on their respective annual mileages and fuel economies.

[ff] Calculated from the annual miles traveled per heavy-duty engine for each year of a engine's life, multiplied by a distribution of engine registrations by year. Estimate of 30,000 miles per year includes all HD weight classes and urban buses.

The per-engine cost of 15 ppm diesel fuel can also be calculated over the lifetime of a engine. However, to calculate a lifetime cost for the average in-use engine, it is necessary to account for the fact that individual engines experience different lifetimes in terms of years that they remain operational. This distribution of lifetimes is the engine survival rate distribution, for which we used registration data from an Arcadis report. The costs of 15 ppm diesel fuel incurred over the lifetime of the average fleet engine can then be calculated as the sum of the costs in individual years as shown in the equation below:

$$LFC = \sum [(AVMT)_i \bullet (SURVIVE)_i \bullet (C) \div (FE)]$$

Where:

LFC	= Lifetime fuel costs in $/engine
$(AVMT)_i$	= Annual engine miles travelled in year i of a engine's operational life[86]
$(SURVIVE)_i$	= Fraction of engines still operating after i years of service[87]
C	= Cost of 15 ppm diesel fuel,$0.045/gal in 2006 and $0.050/gal in 2011
FE	= Fuel economy in miles per gallon (Appendix VI-A)
i	= Engine years of operation, counting from 1 to 30

We used the above equation to calculate lifetime fuel costs separately for LH, MH, HH, and urban buses. We also weighted the per-engine costs for the individual engine classes by their contribution to sales. The results are shown in Table V.C-36 as "undiscounted lifetime costs."

An alternative approach to calculating lifetime per-engine costs of 15 ppm diesel fuel is to discount future year costs. This approach leads to "net present value" lifetime fuel costs, and is a useful means for showing what the average engine owner would have to spend in the first year in order to pay for all future year fuel costs. It also provides a means for comparing the program's costs to its emission reductions in a cost-effectiveness analysis, as described in Chapter VI.

Discounted lifetime fuel costs are calculated in an analogous manner to the undiscounted values, except that each year of the summation is discounted at the average rate of 7 percent. The equation given above can be modified to include this annual discount factor:

$$LFC = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \bullet (C) \div (FE)\}/(1.07)^{i-1}]$$

Once again, we used the above equation to calculate discounted lifetime fuel costs separately for LH, MH, HH, and urban buses, then weighted the per-engine costs for the individual engine classes by their contribution to sales. The results are shown in Table V.C-36 as "discounted lifetime costs."

Table V.C-36. Fleet Average Per-Engine Lifecycle Costs Of Diesel Fuel ($)

	LH	*MH*	*HH*	*UB*	*All*
First year	58	110	390	428	187
Undiscounted lifetime, near-term	801	1497	5395	7426	2583
Undiscounted lifetime, long-term	837	1565	5654	7629	2703
Discounted lifetime, near-term	576	1077	3969	4772	1881
Discounted lifetime, long-term	609	1141	4209	4959	1993

LH = Light heavy duty, MH = Medium heavy duty, HH = Heavy heavy duty,
UB = Urban buses, All = Consumption weighted average of all engine weight classes

D. Combined Total Annual Nationwide Costs

Figure V.D-1 and Table V.D-1 summarize EPA's estimates of total annual costs to the nation for heavy-duty diesel engines, heavy-duty gasoline vehicles, and 15 ppm diesel fuel. The capital costs have been amortized for these analyses. The actual capital investment would occur up-front, prior to and during the initial years of the program, as described previously in this Chapter. The fuel costs shown are for all 15 ppm diesel fuel consumed nationwide, including that consumed in both highway and off-highway applications. Annual aggregate costs change as our new standards are phased-in and projected per-vehicle costs and annual sales change over time. The aggregate fuel costs change due to the temporary compliance option which applies between 2006 and 2010, and as annual fuel consumption changes over time as predicted by the Energy Information Administration. The methodology we used to derive the aggregate costs are described in detail in the previous Sections of this chapter. As shown below, total annual costs increase over the period of the temporary compliance option and peak at about $3.6 billion in 2010. Total annualized costs are projected to increase gradually after 2010 due to projected growth in vehicle sales and fuel consumption.

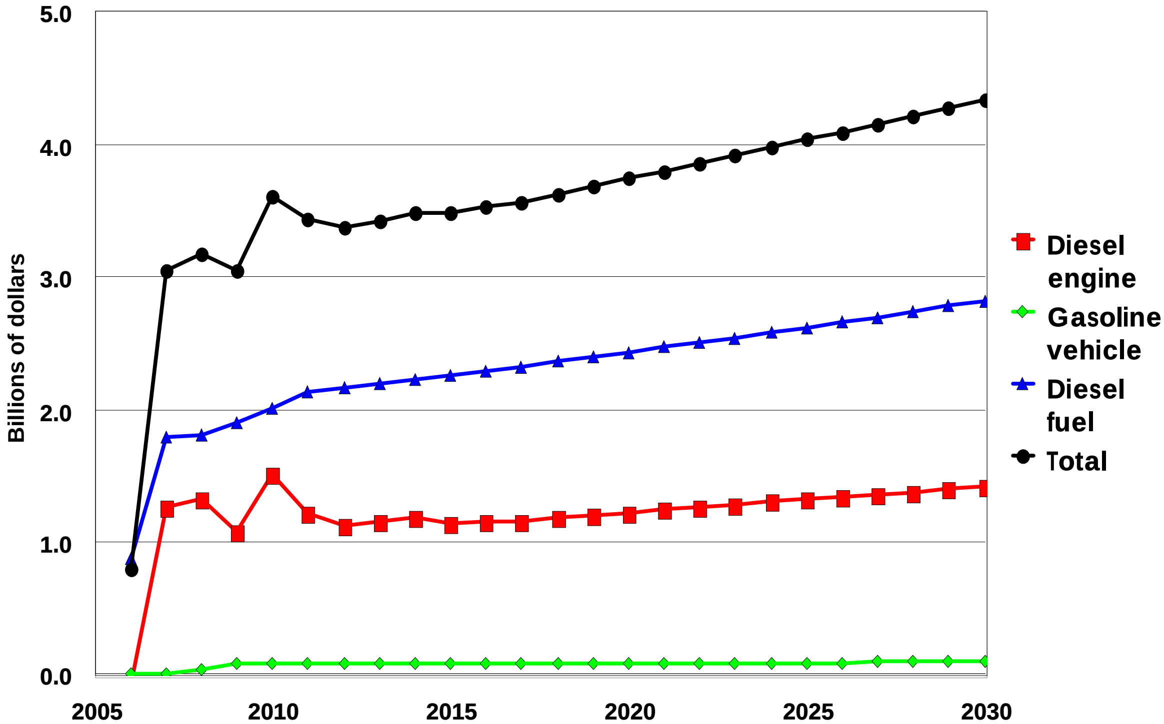

Figure V.D-1. Total annualized costs of heavy-duty diesel engines, heavy-duty gasoline vehicles, and 15 ppm diesel fuel

In Figure V.D-1, aggregate engine costs exhibit notable drops in years 2009 and 2011. The drop in year 2009 is due to the onset of the "learning curve" in the third year of the engine manufacturer's production of engines meeting our new standards. In year 2010, the NOx phase-in ends and the remaining 50 percent of new engines must meet the new standards. This change causes a sudden increase in aggregate costs in 2010. In year 2011, a learning curve adjustment is again made and costs drop once again. Finally, in 2012 the fixed costs expire and the costs drop one last time. Thereafter, costs continue to increase due to growth in the fleet.

Table V.D-1. Total annualized costs of heavy-duty diesel engines, heavy-duty gasoline vehicles, and 15 ppm diesel fuel ($million)

	Diesel engines	*Gasoline vehicles*	*Diesel fuel*	*Total*
2006	(80)	0	880	799
2007	1,266	0	1,786	3,052
2008	1,321	46	1,809	3,177
2009	1,072	80	1,904	3,056
2010	1,520	81	2,014	3,615
2011	1,225	82	2,128	3,434
2012	1,133	83	2,160	3,376
2013	1,157	78	2,192	3,427
2014	1,180	79	2,225	3,484
2015	1,141	80	2,258	3,480
2016	1,156	82	2,292	3,530
2017	1,159	83	2,327	3,568
2018	1,182	84	2,362	3,628
2019	1,205	85	2,397	3,687
2020	1,226	86	2,433	3,746
2021	1,247	87	2,469	3,804
2022	1,268	89	2,506	3,863
2023	1,288	90	2,544	3,921
2024	1,307	91	2,582	3,980
2025	1,326	92	2,621	4,039
2026	1,344	93	2,660	4,098
2027	1,362	94	2,700	4,157
2028	1,380	95	2,741	4,217
2029	1,398	97	2,782	4,276
2030	1,415	98	2,824	4,337

In support of the this rulemaking, the Agency is preparing both a benefit-cost analysis (BCA) and a cost-effectiveness analysis. The BCA presents and compares the social benefits (e.g., avoided adverse health effects) and social costs (e.g., direct compliance expenditures) of the program. Since many of the benefits and costs are manifest in future years, we apply discounting methods to adjust the dollar values of these effects to reflect the finding that society as a whole typically values the realization (or avoidance) of a given effect differently depending on when the effect occurs. Because the BCA reflects the value of benefits and costs from the perspective of society as a whole, we use a 3 percent rate to discount future year effects in our primary analysis. The 3 percent rate is in the 2 to 3 percent range recommended by the Science Advisory Board's Environmental Economics Advisory Committee for use in EPA social benefit-cost analyses, a recommendation incorporated in EPA's new *Guidelines for Preparing Economic Analyses (November 2000)*. OMB Circular A-94 requires us to generate benefit and cost estimates reflecting a 7 percent rate, and results based on OMB's preferred 7 percent rate are also presented to demonstrate the sensitivity of our results to the discount rate assumption.

The BCA focuses on calender year 2030 in its comparison of costs and benefits. The 2030 total program cost shown in Table V.D-1 above was based on a discount rate of 7 percent. Since the BCA requires a 2030 cost which based on a 3 percent discount rate, we developed this separately. Thus the total program cost in calender year 2030 using a discount rate of 3 percent is $4.2 billion. Note that since the discount rate only affects the return on capital investments in any given calender year, and since all engine and vehicle capital investments have been recovered by 2030, the only effect of the discount rate in year 2030 is for fuel costs. As a result, the total program cost under the 3 percent assumption is very close to that under a 7 percent assumption.

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87. See "Update of fleet characterization data for use in MOBILE6," Arcadis Inc., April27, 1998, prepared for U.S. EPA. Registration distribution from Table 4-7 was used to represent survival distribution.

83. Energy Information Administration (EIA), Petroleum Supply Annuals (PSA), Department of Energy,1995-99.

84. “Alternate Markets for Highway Diesel Fuel Components” Muse, Stancil & Co. September 2000

85. API Reported Refining & Marketing Capital Investments, 1990-1998.