Chapter V: Economic Impact

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

This section contains an analysis of the economic impacts of the proposed 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 proposed 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 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 may ultimately take.

Because many of the technologies which we believe will be used by the industry in order to meet the proposed 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 proposed 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 would cause cost impacts to decrease over time, making it appropriate to distinguish between near-term and long term costs. Research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts.[5] 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 cost 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 four service classes of heavy-duty diesel vehicles, as depicted 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 Proposed 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 proposed 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 Catalyst	87	890	0
Catalyzed Diesel Particulate Filter	41	633	0
Closed Crankcase System	0	37	48
Low Sulfur Diesel Fuel	0	0	536
Maintenance Savings	0	0	(153)
Total	128	1,560	431

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	0	570	0
Catalyzed Diesel Particulate Filter	0	389	0
Closed Crankcase System	0	23	31
Low Sulfur Diesel Fuel	0	0	536
Maintenance Savings	0	0	(153)
Total	0	982	414

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	230	1,047	0
Catalyzed Diesel Particulate Filter	98	796	0
Closed Crankcase System	0	42	72
Low Sulfur Diesel Fuel	0	0	1004
Maintenance Savings	0	0	(249)
Total	328	1,885	827

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	0	670	0
Catalyzed Diesel Particulate Filter	0	491	0
Closed Crankcase System	0	27	46
Low Sulfur Diesel Fuel	0	0	1004
Maintenance Savings	0	0	(249)
Total	0	1,188	801

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	191	1,410	0
Catalyzed Diesel Particulate Filter	89	1,028	0
Closed Crankcase System	0	49	268
Low Sulfur Diesel Fuel	0	0	3,704
Maintenance Savings	0	0	(610)
Total	280	2,487	3,362

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	0	902	0
Catalyzed Diesel Particulate Filter	0	638	0
Closed Crankcase System	0	32	172
Low Sulfur Diesel Fuel	0	0	3,704
Maintenance Savings	0	0	(610)
Total	0	1,572	3,266

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	191	1,410	0
Catalyzed Diesel Particulate Filter	89	1,028	0
Closed Crankcase System	0	49	188
Low Sulfur Diesel Fuel	0	0	4,364
Current Oxidation Catalyst Removed	0	(500)	0
Maintenance Savings	0	0	(610)
Total	280	1,987	3,942

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

Item	*Fixed Cost*	*Variable Cost*	*Operating Cost*
NOx Adsorber Catalyst	0	902	0
Catalyzed Diesel Particulate Filter	0	638	0
Closed Crankcase System	0	32	120
Low Sulfur Diesel Fuel	0	0	4,364
Current Oxidation Catalyst Removed	0	(320)	0
Maintenance Savings	0	0	(610)
Total	0	1,252	3,874

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 proposed emission standards detailing the variable costs of the individual technologies. EPA believes that a small set of technologies represent the primary changes manufacturers must make to meet the 2007 model year standards. These technologies are NOx adsorber catalysts for NOx control, catalyzed diesel particulate filters for HC and PM control, and 15 ppm sulfur diesel fuel to enable both of 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, diesel oxidation 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]

Table V.A-3. 2007 NOx Adsorber Cost Estimate [7]

NOx Adsorber Catalyst	*Vehicle Class*		
	LHDD	*MHDD*	*HHDD*
Catalyst Volume	9	12	20
Material Cost			
Substrate	$45	$60	$98
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	$6	$9	$12
Total Direct Cost to Mfr.	$817	$961	$1,296
Warranty Costs (1% Claim Rate)	$22	$26	$34
Mfr. Carrying Cost	$25	$29	$39
Total Cost to Dealer	$864	$1,016	$1,369
Dealer Carrying Cost	$26	$30	$41
Total Cost to Customer	$890	$1,047	$1,410

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.[8]

Table V.A-4. 2007 Catalyzed Diesel Particulate Filter Cost Estimate[9]

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	$6	$9	$12
Total Direct Cost to Mfr.	$618	$770	$987
Warranty Costs (4% Claim Rate)	$16	$20	$25
Mfr. Carrying Cost	$25	$31	$39
Total Cost to Dealer	$659	$821	$1,052
Dealer Carrying Cost	$20	$25	$32
Savings by removing muffler	($45)	($50)	($55)
Total Cost to Customer	$634	$796	$1,029

c. 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.[10] We have estimated the new vehicle cost of this type of closed crankcase system in Table V.A-5.

Table V.A-5. 2007 Closed Crankcase Filtration System Cost Estimate[11]

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 PM/HC control technology and $133 million for the advanced NOx adsorber technology.[12]

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. 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 25 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-6, V.A-7, and V.A-8 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-6. 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	$5,150,406	$0	$0
2003	0	0	$9,420,675	$0	$0	$10,300,813	$0	$0
2004	0	0	$9,420,675	$0	$0	$15,451,219	$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	85,250	$0	$13,212,984	$39	$15,451,219	$7,223,711	$85
2008	346,600	173,300	$0	$1,321,298	$38	$10,300,813	$14,447,422	$83
2009	352,200	264,150	$0	$1,321,298	$38	$5,150,406	$21,671,134	$82
2010	357,800	357,800	$0	$1,321,298	$37	$0	$28,894,845	$81
2011	363,400	363,400	$0	$1,321,298	$36	$0	$28,894,845	$80
2012	369,000	369,000	$0	$0	$0	$0	$21,671,134	$78
2013	374,600	374,600	$0	$0	$0	$0	$14,447,422	$77
2014	380,200	380,200	$0	$0	$0	$0	$7,223,711	$76
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-7. 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	$6,905,663	$0	$0
2003	0	0	$11,161,150	$0	$0	$13,811,325	$0	$0
2004	0	0	$11,161,150	$0	$0	$20,716,988	$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	43,400	$0	$15,654,090	$90	$20,716,988	$9,685,549	$223
2008	176,400	88,200	$0	$15,654,090	$89	$13,811,325	$19,371,098	$220
2009	179,200	134,400	$0	$15,654,090	$87	$6,905,663	$29,056,647	$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	$29,056,647	$207
2013	190,400	190,400	$0	$0	$0	$0	$19,371,098	$203
2014	193,200	193,200	$0	$0	$0	$0	$9,685,549	$201
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-8. 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	$9,051,006	$0	$0
2003	0	0	$16,165,875	$0	$0	$18,102,013	$0	$0
2004	0	0	$16,165,875	$0	$0	$27,153,019	$0	$0
2005	0	0	$16,165,875	$0	$0	$36,204,025	$0	$0
2006	0	0	$16,165,875	$0	$0	$36,204,025	$0	$0
2007	272,800	68,200	$0	$22,673,476	$83	$27,153,019	$12,694,504	$186
2008	277,200	138,600	$0	$22,673,476	$82	$18,102,013	$25,389,009	$183
2009	281,600	211,200	$0	$22,673,476	$81	$9,051,006	$38,083,513	$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	$38,083,513	$172
2013	299,200	299,200	$0	$0	$0	$0	$25,389,009	$170
2014	303,600	303,600	$0	$0	$0	$0	$12,694,504	$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 proposed 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 on the diesel engine may lead to some changes in tooling cost which are accounted for here. The control system itself is expected to use the same hardware systems 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. 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.

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 four 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-9,V.A-10, and V.A-11.

Table V.A-9. 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	$693,750	$0	$0
2007	341,000	85,250	$0	$724,172	$2	$693,750	$181,043	$2
2008	346,600	173,300	$0	$724,172	$2	$693,750	$362,086	$2
2009	352,200	264,150	$0	$724,172	$2	$693,750	$543,129	$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	$543,129	$2
2013	374,600	374,600	$0	$0	$0	$0	$362,086	$2
2014	380,200	380,200	$0	$0	$0	$0	$181,043	$2
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-10. 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	$1,110,750	$0	$0
2007	173,600	43,400	$0	$1,159,459	$7	$1,110,750	$289,865	$7
2008	176,400	88,200	$0	$1,159,459	$7	$1,110,750	$579,729	$7
2009	179,200	134,400	$0	$1,159,459	$6	$1,110,750	$869,594	$6
2010	182,000	182,000	$0	$1,159,459	$6	$0	$1,159,459	$6
2011	184,800	184,800	$0	$1,159,459	$6	$0	$1,159,459	$6
2012	187,600	187,600	$0	$0	$0	$0	$869,594	$6
2013	190,400	190,400	$0	$0	$0	$0	$579,729	$6
2014	193,200	193,200	$0	$0	$0	$0	$289,865	$6
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-11. 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	$1,283,188	$0	$0
2007	272,800	68,200	$0	$1,339,458	$5	$1,283,188	$334,865	$5
2008	277,200	138,600	$0	$1,339,458	$5	$1,283,188	$669,729	$5
2009	281,600	211,200	$0	$1,339,458	$5	$1,283,188	$1,004,594	$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	$1,004,594	$5
2013	299,200	299,200	$0	$0	$0	$0	$669,729	$4
2014	303,600	303,600	$0	$0	$0	$0	$334,865	$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 proposed emission standards. EPA previously developed a methodology for calculating certification costs which results in an estimated certification cost of $30,000 per engine family.[13] 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 each year of the NOx phase-in period 25 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-12, V.A-13, and V.A-14 for each of the heavy-duty vehicle weight classes.

Table V.A-12. 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	85,250	$0	$125,262	$0.4	$120,000	$0	$0
2008	346,600	173,300	$0	$125,262	$0.4	$120,000	$31,316	$0.2
2009	352,200	264,150	$0	$125,262	$0.4	$120,000	$62,631	$0.2
2010	357,800	357,800	$0	$125,262	$0.4	$0	$93,947	$0.3
2011	363,400	363,400	$0	$125,262	$0.3	$0	$93,947	$0.3
2012	369,000	369,000	$0	$0	$0	$0	$93,947	$0.3
2013	374,600	374,600	$0	$0	$0	$0	$62,631	$0.3
2014	380,200	380,200	$0	$0	$0	$0	$31,316	$0.3
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-13. 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	43,400	$0	$266,182	$1.5	$255,000	$0	$0
2008	176,400	88,200	$0	$266,182	$1.5	$255,000	$66,546	$0.8
2009	179,200	134,400	$0	$266,182	$1.5	$255,000	$133,091	$1.0
2010	182,000	182,000	$0	$266,182	$1.5	$0	$199,637	$1.1
2011	184,800	184,800	$0	$266,182	$1.4	$0	$199,637	$1.1
2012	187,600	187,600	$0	$0	$0	$0	$199,637	$1.4
2013	190,400	190,400	$0	$0	$0	$0	$133,091	$1.4
2014	193,200	193,200	$0	$0	$0	$0	$66,546	$1.4
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-14. 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	68,200	$0	$313,156	$1.2	$300,000	$0	$0
2008	277,200	138,600	$0	$313,156	$1.1	$300,000	$78,289	$0.6
2009	281,600	211,200	$0	$313,156	$1.1	$300,000	$156,578	$0.7
2010	286,000	286,000	$0	$313,156	$1.1	$0	$234,867	$0.8
2011	290,400	290,400	$0	$313,156	$1.1	$0	$234,867	$0.8
2012	294,800	294,800	$0	$0	$0	$0	$234,867	$1.1
2013	299,200	299,200	$0	$0	$0	$0	$156,578	$1.1
2014	303,600	303,600	$0	$0	$0	$0	$78,289	$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-15, V.A-16 and V.A-17 below summarize fixed costs in each year of the program.

Table V.A-15. 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	85,250	$14,062,419	$41	$7,404,754	$87	$21,467,173	$128
2008	346,600	173,300	$14,062,419	$41	$14,840,824	$86	$28,903,243	$127
2009	352,200	264,150	$14,062,419	$40	$22,276,894	$84	$36,339,313	$124
2010	357,800	357,800	$14,062,419	$39	$29,712,964	$83	$43,775,383	$122
2011	363,400	363,400	$14,062,419	$39	$29,712,964	$82	$43,775,383	$121
2012	369,000	369,000	$0	$0	$22,308,210	$81	$22,308,210	$81
2013	374,600	374,600	$0	$0	$14,872,140	$79	$14,872,140	$79
2014	380,200	380,200	$0	$0	$7,436,070	$78	$7,436,070	$78
2015	385,800	385,800	$0	$0	$0	$0	$0	$0

Table V.A-16. 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	43,400	$17,079,731	$98	$9,975,414	$230	$27,055,145	$328
2008	176,400	88,200	$17,079,731	$97	$20,017,373	$227	$37,097,104	$324
2009	179,200	134,400	$17,079,731	$95	$30,059,332	$224	$47,139,063	$319
2010	182,000	182,000	$17,079,731	$94	$40,101,291	$220	$57,181,022	$314
2011	184,800	184,800	$17,079,731	$92	$40,101,291	$217	$57,181,022	$309
2012	187,600	187,600	$0	$0	$30,125,878	$214	$30,125,878	$214
2013	190,400	190,400	$0	$0	$20,083,918	$211	$20,083,918	$211
2014	193,200	193,200	$0	$0	$10,041,959	$208	$10,041,959	$208
2015	196,000	196,000	$0	$0	$0	$0	$0	$0

Table V.A-17. 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	68,200	$24,326,090	$89	$13,029,369	$191	$280	$37,355,459
2008	277,200	138,600	$24,326,090	$88	$26,137,027	$189	$277	$50,463,117
2009	281,600	211,200	$24,326,090	$86	$39,244,685	$186	$272	$63,570,775
2010	286,000	286,000	$24,326,090	$85	$52,352,343	$183	$268	$76,678,433
2011	290,400	290,400	$24,326,090	$84	$52,352,343	$180	$264	$76,678,433
2012	294,800	294,800	$0	$0	$39,322,974	$178	$178	$39,322,974
2013	299,200	299,200	$0	$0	$26,215,316	$175	$175	$26,215,316
2014	303,600	303,600	$0	$0	$13,107,658	$173	$173	$13,107,658
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 with this proposal 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 may be 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 proposed 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-18.

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 proposed 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 $0.044/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 per vehicle low sulfur fuel cost of $536 for a light heavy-duty vehicle, $1,004 for a medium heavy-duty vehicle, $3,704 for a heavy heavy-duty vehicle and $4,364 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

We have proposed to eliminate the exception that allows turbo-charged heavy-duty diesel engines to vent crankcase gases directly to the environment, sometimes called open crankcase systems, and have projected that manufacturers will rely on engineered closed crankcase ventilation systems which filter oil from the blow-by gases. 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 total life cycle operating cost for the filter replacements expressed as a net present value in the year of sale is $48, $72, and $268 for light, medium, and heavy heavy-duty vehicles, respectively. Urban bus life cycle operating costs are estimated to be $188. 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) 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 are reported in table V.A-20.

c. 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.

d. 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.[a] 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.[14] 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 envisioned in this proposal. 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 250C). 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 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 are proposing. 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.[15] 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

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

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.[16]

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.[17] 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.[b] 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

[b] 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.

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 $109, for a medium heavy-duty engine it is $210, for a heavy heavy-duty engine it is $764. 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 $91 million in 2010 and $456 million in 2030. These potential benefits (or costs) represent less than 3 percent of the total program cost in 2010 and approximately 13 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 proposed 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 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.[18]

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[19]. 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

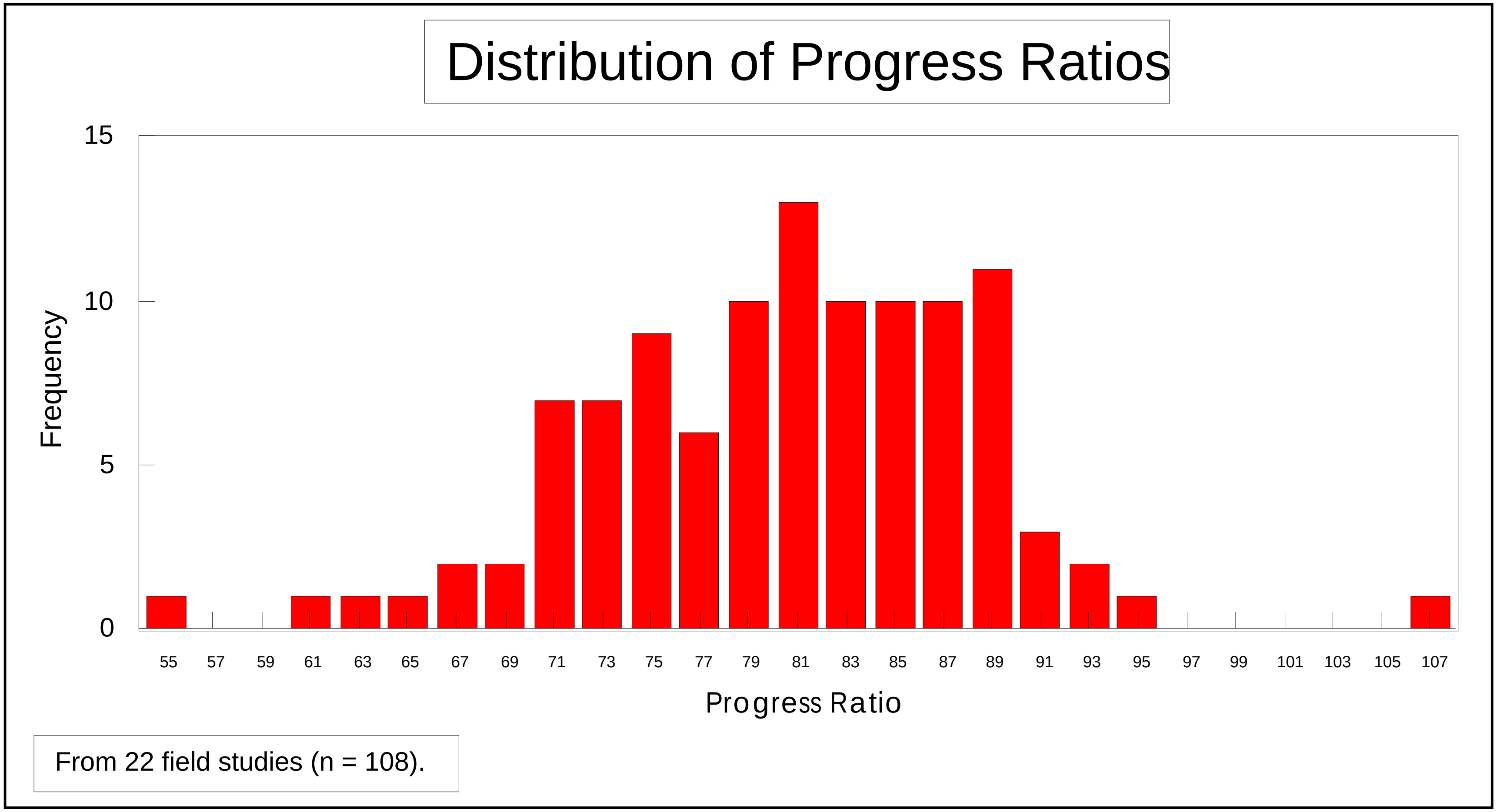

Figure V-1. Distribution of Progress Ratios
(Dutton and Thomas, 1984)

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 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.

Fixed costs for this program have been allocated to four separate groups of vehicle representing vehicles first introduced in each year of the four year 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-18 below.

Table V.A-18. 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	—	$1,688	$431
	2009	20 percent learning curve applied to variable costs	$1,363	$421
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$982	$413
Medium heavy-duty	2007	—	$2,213	$826
	2009	20 percent learning curve applied to variable costs	$1,817	$812
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,188	$800
Heavy heavy-duty	2007	—	$2,768	$3,362
	2009	20 percent learning curve applied to variable costs	$2,251	$3,308
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,572	$3,265
Urban Bus	2007	—	$2,268	$3,942
	2009	20 percent learning curve applied to variable costs	$1,851	$3,904
	2012	Fixed costs expire; 20 percent learning curve has been applied to variable costs	$1,252	$3,874

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-19 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 two percent or less for all vehicle weight classes. Near term vehicle costs on average would be expected to increase by approximately five percent. In the long term vehicle costs would be increased by less than four percent for light heavy-duty vehicles and by two percent or less for medium heavy-duty vehicles, heavy heavy-duty vehicles and urban buses.

Table V.A-19. Baseline Costs for Heavy-Duty Engines and Vehicles [20]

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 proposed 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 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-20 below. Non-annualized costs are also given below in table V.A-21.

Table V.A-20. Estimated Annualized Nationwide Costs for Heavy-Duty Diesel Engines Associated with the Proposed 2007 Emission Standard (1999 dollars)

Calendar Year	*Projected Vehicle Sales*	*Fixed Costs*	*Variable Costs*	*Closed Crankcase Operating Costs*	*Total Costs*
2007	787,400	85,877,777	882,798,579	10,784,898	979,461,254
2008	800,200	116,463,464	1,118,128,087	29,026,256	1,263,617,807
2009	813,000	147,049,151	1,080,354,516	43,194,215	1,270,597,882
2010	825,800	177,634,838	1,279,787,002	54,267,529	1,511,689,369
2011	838,600	177,634,838	1,031,360,767	62,529,356	1,271,524,961
2012	851,400	91,757,061	1,047,078,131	68,615,833	1,207,451,025
2013	864,200	61,171,374	1,062,795,496	74,273,839	1,198,240,709
2014	877,000	30,585,687	1,078,512,861	79,553,799	1,188,652,347
2015	889,800	0	1,094,230,226	84,500,730	1,178,730,956
2016	902,600	0	1,109,947,591	89,154,573	1,199,102,164
2017	915,400	0	1,125,664,956	93,550,426	1,219,215,382
2018	928,200	0	1,141,382,321	97,719,232	1,239,101,553
2019	941,000	0	1,157,099,686	101,687,313	1,258,786,999
2020	953,800	0	1,172,817,051	105,476,108	1,278,293,159
2021	966,600	0	1,188,534,416	109,101,531	1,297,635,947
2022	979,400	0	1,204,251,781	112,574,024	1,316,825,805
2023	992,200	0	1,219,969,145	115,902,410	1,335,871,555
2024	1,005,000	0	1,235,686,510	119,107,871	1,354,794,381
2025	1,017,800	0	1,251,403,875	122,227,639	1,373,631,514
2026	1,030,600	0	1,267,121,240	125,274,608	1,392,395,848
2027	1,043,400	0	1,282,838,605	128,256,553	1,411,095,158
2028	1,056,200	0	1,298,555,970	131,181,774	1,429,737,744
2029	1,069,000	0	1,314,273,335	134,054,476	1,448,327,811
2030	1,081,800	0	1,329,990,700	136,881,389	1,466,872,089
2031	1,094,600	0	1,345,708,065	139,686,830	1,485,394,895
2032	1,107,400	0	1,361,425,430	142,454,197	1,503,879,627
2033	1,120,200	0	1,377,142,795	145,150,919	1,522,293,714
2034	1,133,000	0	1,392,860,160	147,854,706	1,540,714,866
2035	1,145,800	0	1,408,577,524	150,531,763	1,559,109,287

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

Calendar Year	*Fixed Costs*	*Variable Costs*	*Closed Crankcase Operating Costs*	*Total Costs*
2002	57,854,775	0	0	57,854,775
2003	78,961,850	0	0	78,961,850
2004	100,068,925	0	0	100,068,925
2005	121,176,000	0	0	121,176,000
2006	139,314,438	0	0	139,314,438
2007	67,083,913	882,798,579	10,784,898	960,667,390
2008	45,976,838	1,118,128,087	29,026,256	1,193,131,181
2009	24,869,763	1,080,354,516	43,194,215	1,148,418,494
2010	0	1,279,787,002	54,267,529	1,334,054,531
2011	0	1,031,360,767	62,529,356	1,093,890,123
2012	0	1,047,078,131	68,615,833	1,115,693,964
2013	0	1,062,795,496	74,273,839	1,137,069,335
2014	0	1,078,512,861	79,553,799	1,158,066,660
2015	0	1,094,230,226	84,500,730	1,178,730,956
2016	0	1,109,947,591	89,154,573	1,199,102,164
2017	0	1,125,664,956	93,550,426	1,219,215,382
2018	0	1,141,382,321	97,719,232	1,239,101,553
2019	0	1,157,099,686	101,687,313	1,258,786,999
2020	0	1,172,817,051	105,476,108	1,278,293,159
2021	0	1,188,534,416	109,101,531	1,297,635,947
2022	0	1,204,251,781	112,574,024	1,316,825,805
2023	0	1,219,969,145	115,902,410	1,335,871,555
2024	0	1,235,686,510	119,107,871	1,354,794,381
2025	0	1,251,403,875	122,227,639	1,373,631,514
2026	0	1,267,121,240	125,274,608	1,392,395,848
2027	0	1,282,838,605	128,256,553	1,411,095,158
2028	0	1,298,555,970	131,181,774	1,429,737,744
2029	0	1,314,273,335	134,054,476	1,448,327,811
2030	0	1,329,990,700	136,881,389	1,466,872,089
2031	0	1,345,708,065	139,686,830	1,485,394,895
2032	0	1,361,425,430	142,454,197	1,503,879,627
2033	0	1,377,142,795	145,150,919	1,522,293,714
2034	0	1,392,860,160	147,854,706	1,540,714,866
2035	0	1,408,577,524	150,531,763	1,559,109,287

B. Economic Impact of the Proposed 2007 Model Year Heavy-Duty Gasoline Standards

This chapter contains an analysis of the economic impacts of the proposed emission standards for 2007 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 of the proposed regulations. Finally, an analysis of the aggregate cost to society of the proposed regulations 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 proposed 2004 model year as a baseline from which changes would be made to comply with the proposed 2007 standards. [64 FR 58472] That is, we have identified the changes we expect to be made to the assumed 2004 baseline vehicles in complying with the standards proposed for the 2007 model year. The 2004 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 2007 model year are consistent with those expected to meet the California LEV-II medium-duty vehicle standards and our Tier 2 standards.[c] The catalyst system costs of these technologies are taken from the proposed 2004 RIA, which are based on a report done for EPA by Arcadis Geraghty & Miller.[21] 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 proposed 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 estimated cost for each element comprising the catalyst are the supplier 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 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

[c] 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 into the heavy-duty gasoline fleet; therefore, the types of technology packages are expected to be very similar.

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.[22] 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 Proposed 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 our proposed 2007 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 proposed 2004 standards. Table 5.B-1 shows both the expected 2004 technology packages, the baseline for this analysis, and the expected 2007 technologies for both complete and incomplete gasoline vehicles. The expected technologies for 2007 are consistent between vehicles and engines; we make this assumption based on the equivalency of the proposed standards for vehicles and engines.

This table only shows the technologies which are expected to change in some way or be applied in different percentages to meet the 2007 standards. A technology like sequential multi-port fuel injection, while important to meeting the proposed standards, is expected on 100 percent of the 2004 vehicles and engines, and its design is not expected to fundamentally change for 2007. 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 2007 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 proposed 2007 standards.

Table V.B-1. 2004 and Expected 2007 Technology Packages for Heavy-Duty Gasoline Vehicles excluding Medium-Duty Passenger Vehicles

Technology	*2004 Complete Vehicles*	*2004 Incomplete Vehicles (Engine-Based)*	*2007 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 2004 reflects OBD requirements for all HDGEs. However, OBD is only proposed to apply to 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 proposed 2007 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. These are weighted where appropriate assuming that standard engines would account for 75 percent of sales, and larger engines would account for 25 percent of sales.

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 2004 and 2007 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 2004, we estimated that: 13 percent of vehicles would employ a single underfloor catalyst; 50 percent of vehicles would employ dual underfloor catalysts; and, 37 percent of vehicles would employ dual close-coupled with dual underfloor catalysts. For 2007, we expect that 50 percent of vehicles would employ dual underfloor with the remaining 50 percent employing dual close-coupled catalysts with a dual underfloor. For engine based systems in 2004, we estimated that: 13 percent of engines would employ a single underfloor catalyst; and, 87 percent would employ dual underfloor catalysts. For 2007, 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 2007.[23]

ii. Changes in 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 2004, we estimated 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 2007, we estimate that the ratio will change to 1/14/1, consistent with Tier 2, at a loading of 5 g/L.[24]

We have also estimated that catalyst volumes will increase. For 2004, we assumed catalyst volumes would be 4.8 liters for the standard engines and 5.8 liters for the larger engines. Because the 2007 standards are significantly 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.[d] While the catalyst volumes we are assuming for 2007 may be low for some applications and high for others (1998 model year certified 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.

[d] 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 durability characteristics.

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

Vehicles

	Projected 2004 Catalyst Volume (L)	Projected 2007 Catalyst Volume (L)	2004 Catalyst Loading (g/L)	2007 Catslyst Loading (g/L)	2004 Pt/Pd/Rh	2007 Pt/Pd/Rh	2004 Pt (g)	2004 Pd (g)	2004 Rh (g)	2007 Pt (g)	2007 Pd (g)	2007 Rh (g)	Increased Pt (g)	Increased Pd (g)	Increased Rh (g)	2004 PGM Cost ($)	2007 PGM Cost ($)
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	280.84	368.29
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	339.35	453.28

Engines

	Projected 2004 Catalyst Volume (L)	Projected 2007 Catalyst Volume (L)	2004 Catalyst Loading (g/L)	2007 Catslyst Loading (g/L)	2004 Pt/Pd/Rh	2007 Pt/Pd/Rh	2004 Pt (g)	2004 Pd (g)	2004 Rh (g)	2007 Pt (g)	2007 Pd (g)	2007 Rh (g)	Increased Pt (g)	Increased Pd (g)	Increased Rh (g)	2004 PGM Cost ($)	2007 PGM Cost ($)
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	315.95	368.29
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	381.77	453.28

Precious Metal Costs (from Tier 2 Final Rule)

	$/Troy Oz	$/gram
Platinum	412	12.58
Paladium	390	13.29
Rhodium	868	28.00

iii. Changes in Catalyst Washcoat

In addition to the changes to precious metals just discussed, we expect that the proposed 2007 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 assumed that a 75/25 ratio of ceria to alumina would be used in complying with the 2004 vehicle-based standards and that an even higher 80/20 ratio of ceria to alumina would be used in complying with the proposed engine-based standards. For 2007, 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 2004, we assumed an average loading of 190 g/L for vehicle-based systems, and 220 g/L for engine-based systems. For 2007, 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 in compliance with the 2004 standards. We are assuming the same for the 2007 standards. The following linear relationship has been shown to be accurate for ceramic substrates sized from 0.5 L to 4 L:

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

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 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 estimated for 2007 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 2004 and 2007 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 2007 because we do not expect any such applications in 2007. The costs for the 2004 vehicles and engines shown in Table V.B-3 differ somewhat from those shown in the recently proposed 2004 rulemaking. The difference is primarily due to the updated precious metal costs used in this analysis.

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

Single Underfloor Catalyst System

	Complete Vehicles				Incomplete Vehicles			
	2004 Vehicle		2007 Vehicle		2004 Engine		2007 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	$281	$339			$316	$382		
Can (18 gauge 409 SS)**	$5	$5			$5	$5		
Total Material Cost	$334	$403			$373	$449		
Labor	$4	$4			$6	$6		
Labor Overhead @ 40%	$2	$2			$2	$2		
Supplier Markup @ 29% ***	$8	$9			$10	$11		
Manufacturer Cost	$348	$418			$392	$469		
Manufacturer Carrying Cost @ 4%	$14	$17			$16	$19		
Total Cost to Dealer	**$362**	**$434**			**$407**	**$488**		
Incremental Cost			n/a	n/a			n/a	n/a

Dual Underfloor Catalyst System

	Complete Vehicles				Incomplete Vehicles			
	2004 Vehicle		2007 Vehicle		2004 Engine		2007 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	$281	$339	$368	$453	$316	$382	$368	$453
Can (18 gauge 409 SS)**	$5	$6	$6	$7	$5	$6	$6	$7
Total Material Cost	$334	$404	$431	$529	$373	$450	$431	$529
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	$353	$426	$459	$563	$401	$481	$459	$563
Manufacturer Carrying Cost @ 4%	$14	$17	$18	$23	$16	$19	$18	$23
Total Cost to Dealer	**$367**	**$443**	**$478**	**$586**	**$417**	**$500**	**$478**	**$586**
Incremental Cost			$110	$143			$61	$86

Dual Close-coupled with Dual Underfloor Catalyst System

	Complete Vehicles				Incomplete Vehicles			
	2004 Vehicle		2007 Vehicle		2004 Engine		2007 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	$281	$339	$368	$453	$316	$382	$368	$453
Can (18 gauge 409 SS)**	$6	$7	$7	$8	$7	$8	$7	$8
Total Material Cost	$339	$408	$434	$533	$375	$452	$434	$533
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	$371	$444	$476	$580	$415	$497	$476	$580
Manufacturer Carrying Cost @ 4%	$15	$18	$19	$23	$17	$20	$19	$23
Total Cost to Dealer	**$386**	**$462**	**$495**	**$603**	**$431**	**$517**	**$495**	**$603**
Incremental Cost			$109	$141			$64	$86

*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 2004 NPRM RIA; 2007 from Arcadis 9/30/98.
***Not applied to precious metals or Substrate (substrate costs already include supplier markup).
****From 2004 NRPM 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 2004, we assumed that 13 percent of heavy-duty gasoline vehicles and engines would employ dual heated oxygen sensors, and 87 percent would employ four heated oxygen sensors. For 2007, we have assumed that all vehicles and engines would 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 was not expected to change as a result of the 2004 standards. For 2007, we are assuming that 100 percent of vehicles and engines would 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 2007.

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 2004, we estimated a secondary air injection usage rate of 30 percent on vehicles and 50 percent on engines. For 2007, 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 2004, we estimated that they would be used on 40 percent of the vehicles, and none of the engines. For 2007, we are estimating that they will be used on 60 percent of vehicles having a dual close-coupled with a dual underfloor catalyst system, and 100 percent of vehicles 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 proposed evaporative emission standards would 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.

As discussed in Chapter III.C, we estimate the costs of complying with the proposed heavy-duty evaporative emission standards at $4 per vehicle . This cost is applied to all heavy-duty gasoline vehicles regardless of their current ability to comply with the proposed standard because we assume manufacturers will make some efforts to improve upon compliance margins.

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					
	2004 Vehicle		2007 Vehicle		Increment		2004 Engine		2007 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	$374	$449	$486	$594	$113	$145	$416	$499	$486	$594	$71	$96
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	$4	$4	$4	$4	$0	$0	$4	$4	$4	$4
Total Dealer Cost	$492	$568	$661	$769	$169	$201	$534	$617	$657	$765	$123	$148
Dealer Carrying Cost @ 3%	$15	$17	$20	$23			$16	$19	$20	$23		
Total Cost to the Consumer	$507	$585	$681	$792			$550	$636	$677	$788		
Increased Cost to the Consumer					**$174**	**$207**					**$127**	**$152**

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

The costs for the 2004 vehicles and engines shown in Table V.B-4 differ somewhat from those shown in the recently proposed 2004 rulemaking. The difference is due to the updated precious metal costs used in this analysis. As Table V.B-4 shows, the incremental technology costs for heavy-duty gasoline vehicles and engines associated with the proposed 2007 standards are $174 and $207 for standard and large sized engines in vehicle-based applications, respectively, and $127 and $152 for standard and large sized engines in engine-based applications, respectively.

Weighting these costs assuming a standard/large split of 75/25 percent, would give incremental costs of $182 for complete vehicles and $133 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 after the third year. We applied the learning curve reduction only once for gasoline because we anticipate that, for the most part, the 2007 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 due to 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 2009 model year. Thereafter, the incremental technology costs would fall to $165 and $119 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 proposed 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 proposed 2007 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 would cover about 25 engineering staff person years and about 20 development vehicles.[e] 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 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 all engine families certified as complete vehicles over 10,000 pounds will require R&D efforts because our proposed 2007 standards are more stringent in that weight class than are the LEV-II 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, 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.[25] We have applied tooling costs only to those engines requiring R&D efforts.

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

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

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 would have to be generated for the new 2007 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.[26] This estimate does not account for the ability of manufacturers, in some 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 $0.43 for complete vehicle configurations and $1.62 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.

c. In-use Testing Costs

The 2004 rule accounted for an in-use testing cost. Using cost information developed in support of our CAP 2000 regulations, the 2004 rule projected that the in-use testing requirement would cost $1 per vehicle. Since this cost is accounted for in the 2004 rule, including it here would be effectively double counting in-use testing costs.

5. Summary of Heavy-Duty Gasoline Costs

Table V.B-5 contains a summary of per-vehicle costs associated with the proposed 2007 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 have been weighted assuming a standard/large engine split of 75 percent/25 percent, and a Complete/Incomplete vehicle split of 71 percent/29 percent. The costs are presented as incremental cost increases from the 2004 system costs.

Table V.B-5. Summary of Incremental Costs to Meet the Proposed 2007 Heavy-Duty Gasoline Emission Standards

		Complete Vehicles	*Incomplete Vehicles*	*HDGVs*
Near Term	Technology/Hardware	$182	$133	$168
	Fixed Costs	$10	$25	$14
	Incremental Cost	**$192**	**$158**	**$182**
Long Term	Technology/Hardware	$165	$119	$152
	Fixed Costs	$0	$0	$0
	Incremental Cost	**$165**	**$119**	**$152**

6. Total Nationwide Costs for 2007 Heavy-Duty Gasoline Vehicles

The above analyses developed incremental per vehicle manufacturer and consumer cost estimates for heavy-duty gasoline vehicles designed to the proposed 2007 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 proposed 2007 standards. Table V.B-6 presents the results of this analysis.

Table V.B-6. Estimated Annualized Nationwide Vehicle Costs Associated with the Proposed 2007 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	$6,213,290	100%	$71,238,535	$0	$77,451,825	$182
2008	431,520	$6,213,290	100%	$72,406,379	$0	$78,619,670	$182
2009	438,480	$6,213,290	100%	$66,520,131	$0	$72,733,421	$166
2010	445,440	$6,213,290	100%	$67,576,006	$0	$73,789,296	$166
2011	452,400	$6,213,290	100%	$68,631,881	$0	$74,845,172	$165
2012	459,360	$0	100%	$69,687,756	$0	$69,687,756	$152
2013	466,320	$0	100%	$70,743,631	$0	$70,743,631	$152
2014	473,280	$0	100%	$71,799,507	$0	$71,799,507	$152
2015	480,240	$0	100%	$72,855,382	$0	$72,855,382	$152
2016	487,200	$0	100%	$73,911,257	$0	$73,911,257	$152
2017	494,160	$0	100%	$74,967,132	$0	$74,967,132	$152
2018	501,120	$0	100%	$76,023,007	$0	$76,023,007	$152
2019	508,080	$0	100%	$77,078,882	$0	$77,078,882	$152
2020	515,040	$0	100%	$78,134,757	$0	$78,134,757	$152
2021	522,000	$0	100%	$79,190,632	$0	$79,190,632	$152
2022	528,960	$0	100%	$80,246,507	$0	$80,246,507	$152
2023	535,920	$0	100%	$81,302,382	$0	$81,302,382	$152
2024	542,880	$0	100%	$82,358,258	$0	$82,358,258	$152
2025	549,840	$0	100%	$83,414,133	$0	$83,414,133	$152
2026	556,800	$0	100%	$84,470,008	$0	$84,470,008	$152
2027	563,760	$0	100%	$85,525,883	$0	$85,525,883	$152
2028	570,720	$0	100%	$86,581,758	$0	$86,581,758	$152
2029	577,680	$0	100%	$87,637,633	$0	$87,637,633	$152
2030	584,640	$0	100%	$88,693,508	$0	$88,693,508	$152
2031	591,600	$0	100%	$89,749,383	$0	$89,749,383	$152
2032	598,560	$0	100%	$90,805,258	$0	$90,805,258	$152
2033	605,520	$0	100%	$91,861,133	$0	$91,861,133	$152
2034	612,480	$0	100%	$92,917,009	$0	$92,917,009	$152
2035	619,440	$0	100%	$93,972,884	$0	$93,972,884	$152

As shown in Table V.B-6, we have projected a total cost starting at $77 million in 2007 and peaking at $79 million in 2008 after which time variable costs decrease due to the learning curve. Costs then gradually increase through 2011 as projected sales increase, after which time the costs again 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.[27]

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 used a mix of 71 percent complete vehicles and 29 percent incomplete vehicles based on these sales data, excluding the 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-7 shows the non-annualized costs.

Table V.B-7. Estimated Non-Annualized Nationwide Vehicle Costs Associated with the Proposed 2007 Heavy-Duty Gasoline Emission Standards

Year	Projected Sales	Fixed Costs	Fraction of Fleet Complying	Variable Costs	Operating Costs	Total Cost
2004	403,680	$4,166,667	0%	$0	$0	$4,166,667
2005	410,640	$4,166,667	0%	$0	$0	$4,166,667
2006	417,600	$14,946,667	0%	$0	$0	$14,946,667
2007	424,560	$0	100%	$71,238,535	$0	$71,238,535
2008	431,520	$0	100%	$72,406,379	$0	$72,406,379
2009	438,480	$0	100%	$66,520,131	$0	$66,520,131
2010	445,440	$0	100%	$67,576,006	$0	$67,576,006
2011	452,400	$0	100%	$68,631,881	$0	$68,631,881
2012	459,360	$0	100%	$69,687,756	$0	$69,687,756
2013	466,320	$0	100%	$70,743,631	$0	$70,743,631
2014	473,280	$0	100%	$71,799,507	$0	$71,799,507
2015	480,240	$0	100%	$72,855,382	$0	$72,855,382
2016	487,200	$0	100%	$73,911,257	$0	$73,911,257
2017	494,160	$0	100%	$74,967,132	$0	$74,967,132
2018	501,120	$0	100%	$76,023,007	$0	$76,023,007
2019	508,080	$0	100%	$77,078,882	$0	$77,078,882
2020	515,040	$0	100%	$78,134,757	$0	$78,134,757
2021	522,000	$0	100%	$79,190,632	$0	$79,190,632
2022	528,960	$0	100%	$80,246,507	$0	$80,246,507
2023	535,920	$0	100%	$81,302,382	$0	$81,302,382
2024	542,880	$0	100%	$82,358,258	$0	$82,358,258
2025	549,840	$0	100%	$83,414,133	$0	$83,414,133
2026	556,800	$0	100%	$84,470,008	$0	$84,470,008
2027	563,760	$0	100%	$85,525,883	$0	$85,525,883
2028	570,720	$0	100%	$86,581,758	$0	$86,581,758
2029	577,680	$0	100%	$87,637,633	$0	$87,637,633
2030	584,640	$0	100%	$88,693,508	$0	$88,693,508
2031	591,600	$0	100%	$89,749,383	$0	$89,749,383
2032	598,560	$0	100%	$90,805,258	$0	$90,805,258
2033	605,520	$0	100%	$91,861,133	$0	$91,861,133
2034	612,480	$0	100%	$92,917,009	$0	$92,917,009
2035	619,440	$0	100%	$93,972,884	$0	$93,972,884

C. Benefits of Low Sulfur 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 would apply to new vehicles and to the existing heavy-duty vehicle fleet beginning in 2006 when the fuel is proposed to be 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-1 and are described in more detail in the following sections.

Table V.C-1 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 would be quite small. However for vehicles produced in the years immediately preceding the introduction of low-sulfur fuel the savings would 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.

1. 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 would 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.[28]

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.

2. 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 would probably extend oil drain intervals. Based on information from some engine manufacturers and others, we have assumed that engine oil change intervals would 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-2.

Table V.C-2 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.[29]

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 are estimated to be $153 for light heavy-duty vehicles, $249 for medium heavy-duty vehicles and $559 for heavy heavy-duty vehicles.

3. 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, would 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, as proposed here, 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 aggregate savings for vehicles sold in 2004-2006 and rebuilt in 2009-2011 are shown in Table V.C-3. The aggregate savings for vehicles built beginning in 2007 and rebuilt beginning in 2012 are presented in Table V.C-4. These savings can also be expressed in terms of a net present value in the year of vehicle sale of $51.

Table V.C-3 Cost Savings to the Existing Fleet for Reduced EGR System Replacment 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-4 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).

4. 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-5. 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-5 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.[30]

5. 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.

6. 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 existing fleet (pre-2007 vehicles) in Table V.C-6 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 and are presented in Table V.C-7. 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-6 Aggregate Savings to the Existing Fleet (pre-2007 fleet) Made Possible by Low Sulfur Diesel Fuel

Calendar Year	*Aggregate Savings*
2006	$147,817,260
2007	$300,137,233
2008	$292,550,695
2009	$273,689,435
2010	$264,978,663
2011	$234,613,061
2012	$207,948,971
2013	$163,215,129
2014	$142,360,025
2015	$124,044,931
2016	$107,964,227
2017	$93,846,769
2018	$81,452,157
2019	$70,568,099
2020	$61,008,920
2021	$52,616,869
2022	$45,262,151
2023	$38,833,190
2024	$33,230,120
2025	$28,351,621
2026	$24,102,405
2027	$20,391,663
2028	$17,143,711
2029	$14,294,965
2030	$11,787,060
2031	$9,577,692
2032	$7,620,925
2033	$5,903,258
2034	$4,308,404
2035	$2,905,183

Table V.C-7 Aggregate Savings for the New Fleet (2007 and later) Made Possible by Low Sulfur Diesel Fuel

Calendar Year	*Aggregate Savings*
2006	$0
2007	$25,397,440
2008	$67,507,675
2009	$105,489,726
2010	$139,964,498
2011	$171,559,482
2012	$200,449,015
2013	$248,287,755
2014	$273,022,792
2015	$295,900,057
2016	$317,142,431
2017	$336,946,872
2018	$355,487,509
2019	$372,916,084
2020	$389,362,886
2021	$404,936,131
2022	$419,723,234
2023	$433,798,473
2024	$447,251,766
2025	$460,197,606
2026	$472,700,644
2027	$484,817,488
2028	$496,597,450
2029	$508,083,739
2030	$519,313,990
2031	$530,363,269
2032	$541,211,098
2033	$551,807,127
2034	$562,330,836
2035	$572,706,555

D. Diesel Fuel Desulfurization 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

Our cost estimate for desulfurizing diesel fuel is based on hydrotreating process operations and capital cost information received from two licensors of conventional distillate desulfurization technology.[f] In addition, information obtained from two other vendors of diesel desulfurization technology further corroborated the information provided by the first two vendors. The desulfurization costs were estimated for a "characteristic" refinery, which represents the average difficulty of desulfurizing diesel fuel. The characteristic refinery processes an average volume of highway diesel fuel which is of average desulfurization difficulty intended to represent all of the refineries in the U.S. The desulfurization difficulty for the characteristic refinery is defined by the fraction of light cycle oil (LCO) which that refinery blends into its distillate pool. On average highway diesel fuel manufactured by U.S refineries contains about 23 percent LCO, so this is the fraction of LCO which we assumed is treated by our characteristic refinery. Since LCO is the most difficult blendstock to hydrotreat, and because of our findings that the fraction in the highway diesel pool varies substantially from refinery to refinery, we also did a sensitivity analysis for refineries which have no LCO in its highway pool.

We presume that the characteristic refinery starts with an highway diesel fuel sulfur level of 340 ppm and it is reduced 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 meet the proposed 15 ppm cap standard. Construction, operating and feedstock costs for each characteristic refinery are based on national average costs.

We estimate the diesel desulfurization cost for the characteristic refinery based on the information provided by the vendors. We also estimated the desulfurization cost for a "typical" small refinery. While their costs are averaged in with the characteristic refinery outlined above, we estimate their cost to comply with the proposed sulfur standard separately because they are generally considered to be faced with the highest per-gallon cost by virtue of their small size. Thus, the analysis of small refiners will help us understand how the cost for these most challenged refineries differs from that of the typical sized refinery.

[f] 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.

b. Derivation of LCO Fraction for the Characteristic 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 127 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).[31] 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.[32] 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. We don't have 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 simplistically 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 50 percent. The distribution of refineries by fraction of LCO is summarized in Table V.D-1.

Table V.D-1. Cumulative Number of Refineries and Volume of Onroad Diesel Fuel Produced by those Refineries with Various Fractions of Light Cycle Oil in their Distillate

	Percentage of LCO in Distillate Pool								
	0%	≤10%	≤15%	≤20%	≤25%	≤30%	≤40%	≤50%	≤60%
Number of Refineries	60	60	61	64	73	90	114	123	126
Cumulative Percentage of US Onhighway Diesel Volume	38	38	39	41	48	65	88	98	99

In Table V.D-1, our analysis shows that distillate contains anywhere from no LCO to 60 percent LCO. Our analysis also shows that 60 U.S. refineries which produce about 38 percent of the distillate in the U.S. blend no LCO into this distillate, while the distillate from the remaining 67 refineries averages about 30 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.

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 three 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. Another vendor provided significant cost information for 23 percent LCO in diesel fuel. 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 diesel fuel containing 23 percent LCO, which is the average amount of LCO in highway diesel fuel, and as a sensitivity, no LCO in the diesel fuel.

The information provided by the vendors is based on typical diesel fuels, however, in reality diesel fuel (especially LCO) varies in desulfurization difficulty based on the amount of sterically hindered compounds present in the fuel. The vendors provided cost information based on diesel fuels with T-90 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.[33] Since our analysis attempts to capture the average cost to the industry, it is appropriate to base our cost analysis on a typical or average diesel fuel. This discussion is particularly relevant with respect to the sensitivity analysis. At face value, our analysis of the cost of desulfurizing diesel fuel without LCO may appear to be the easiest case. This is not so as even straight run has a significant amount of sterically hindered compounds provided that the distillation endpoint is high enough, which it was for the feedstocks evaluated by the vendors. There are likely to be easier, no LCO diesel fuels to treat if the endpoint is lower than that evaluated by the vendors, and lower endpoint fuels do exist according to the fuel surveys.

Since other cracked stocks (coker and visbreaker distillate) contain a higher concentration of sulfur than straight run distillate we considered including these cracked stocks in with LCO. However, the vendors stated that much of this sulfur is not from sterically hindered compounds like that found in LCO so we did not consider their concentration to be a determining factor in this analysis. However, the operating and cost information received from the vendors generally applied to distillates which contained both LCO and other cracked stocks, as is typically the case commercially.

The diesel desulfurization cost information was generated for two groups of refineries, one group, which is intended to represent a typical U.S. refinery, blends 23 percent LCO into their diesel fuel, and the second group, which is formed for a sensitivity analysis, blends no LCO in their diesel fuel. We considered performing a second sensitivity analysis for refineries with more than 23 percent LCO in their diesel fuel. However, the projected refining cost of meeting the proposed 15 ppm cap for the 23 percent and no LCO cases were not significantly different to warrant additional sensitivity analyses. Furthermore, we only had additional cost information for treating diesel fuel with 30 percent LCO which is not that much different from a 23 percent LCO diesel fuel. In addition, we modeled the group of SBREFA refineries separately as these refineries are generally the most challenged. Only 10 percent of the diesel fuel produced by the SBREFA refineries contains no LCO. The other 90 percent of the diesel fuel from these small refineries is assumed to contain 23 percent LCO as well. These refinery groups and their key features are summarized in Table V.D-2 below:

Table V.D-2. Breakdown of U.S. Refineries According to the Presence of LCO in Their Distillate Pool

	No LCO in Diesel	*LCO in Diesel*
Total Number of U.S. Refineries	60	67
Percentage of Highway Diesel Fuel Produced	38	62

c. Technology and Cost Inputs

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.[34] [35] [36] 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.

Late in our cost development process, we obtained the submissions made to the National Petroleum Council (NPC) by a number of diesel desulfurization technology vendors.[37] Of the five vendors which provided information to the NPC; we had met with four of them plus the NPC submissions included information from one additional vendor: Akzo Nobel, Criterion, Haldor Topsoe, UOP and IFP (the vendor which we did not meet with). 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 the 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 lower estimates of hydrogen consumption, as reflected by the majority of the vendors. Similarly, API has indicated that they believe that very high hydrotreating pressures (e.g., 1200 psi or more) will be necessary to reduce sulfur below 30 ppm on average. None of the vendors projected that pressures more than 900 psi would be necessary and most of the vendors projected that 600 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 low to moderate pressure requirements.

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, as such 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,[g] chose to estimate operating and capital costs for a two-stage revamp, which is operated at a higher pressure.[h] 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 refiners. Thus, we based our rule on the cost of both vendors representing both approaches and we

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

[h] 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.

weighted them the same. 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.

Table V.D-3. Vendor Specified Capital Investments Projected to be Used to Achieve Low Sulfur Diesel Fuel

	Vendor A	*Vendor B*
Desulfurize diesel fuel down to 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
Desulfurize diesel fuel down to 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
Desulfurize diesel fuel to under 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

The information provided by the vendors for the 23 percent LCO case and a no LCO sensitivity case is summarized below in Tables V.D-4 & 5. This information was provided either for either revamp or for a grassroots unit, which is indicated.

Table V.D-4. Process Operations Information for Diesel Desulfurization Processes Treating Diesel Fuel with 23 percent Light Cycle Oil as Provided by Diesel Desulfurization Technology Vendors (Information is for both a Retrofit of an Existing Diesel Hydrotreater and a Grassroots Unit)

	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 BPSD (MMbbl/day)	25,000	25,000	25,000	31,200	31,200	31,200
Capital Cost (ISBL) (MM$)	15 - 18	15 - 18	+1 more than at 10 ppm	5.5	7	15
LHSV (Liquid Hour Space Velocity (Hr^{-1})	2.5 1.25*	1.5 1.0*	0.8*	1.5	0.9	NP
Chemical Hydrogen Consumption (SCF/bbl)	100	160	+13 more than at 10 ppm	70	115	NP
Electricity (KwH/bbl)	0.30	0.36	NP	0.5	0.6	NP
HP Steam (Lb/bbl)	-	-	-	-	-	-
Fuel Gas (BTU/bbl)	-2.2**	-2.9	NP	100	100	NP
Catalyst Cost ($/bbl)	0.06	0.08	NP	0.14	0.41	NP
Yield Loss (wt%) Diesel Naphtha LPG Fuel Gas	-1.42* +0.89* +0.05* +0.09*	-1.51* +1.06* +0.06* +0.10*	NP NP NP NP	Used Vendor A's Information	Used Vendor A's Information	Used Vendor A's Information

NP = not provided
* information provided for a grassroots unit
** information provided for achieving 30 ppm; value is negative to indicate exothermic reaction

Table V.D-5. Process Operations Information for Diesel Desulfurization Processes Treating Diesel Fuel with no Light Cycle Oil as Provided by a Diesel Desulfurization Technology Vendor (Information is for both a Retrofit of an Existing Diesel Hydrotreater and a Grassroots Unit)

	Vendor A *50 ppm* *800 psi Hydrotreating*	*Vendor A* *10 ppm* *800 psi Hydrotreating*
Capacity BPSD (MMbbl/day)	25,000	25,000
Capital Cost (ISBL) (MM$)	15 - 18	15 - 18
LHSV (Liquid Hour Space Velocity (Hr^{-1})	1.6*	1.25*
Hydrogen Consumption (SCF/bbl)	210*	225*
Electricity (KwH/bbl)	NP	NP
HP Steam (Lb/bbl)	-	-
Fuel Gas (BTU/bbl)	NP	NP
Catalyst Cost ($/BPSD)	34*	45*
Yield Loss (%) Diesel Naphtha LPG Fuel Gas	NP	NP

NP = not provided
* information provided for a grassroots unit

Some of the information provided by the vendors is for a revamp and therefore we used in our cost model directly, however, some of the information is for a grassroots unit and it must be adjusted to reflect the impact or cost of a revamp. In other cases, no information was presented at all so we developed a method for estimating the revamp costs. 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 volume projected to be necessary to accomplish the required desulfurization. Thus, using the inverse ratio of LHSV is the same as the ratio of catalyst and reactor volume, which should be good surrogate for the ratio of costs. We did not receive information from Vendor B for desulfurizing non-LCO containing 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 non-LCO feed compared to a 23 percent LCO feed. Using information from both vendors for estimating the cost for the sensitivity analysis results in a better comparison with the case with 23 percent LCO. For meeting the proposed 15 ppm cap standard, which means 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 each table.

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.[38] [39] 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 adjusted vendor capital and operating cost information is summarized in Tables V.D-6. and V.D-7. below.

Table V.D-6. Process Operations Information for Diesel Desulfurization Processes Treating Diesel Fuel with 23 percent Light Cycle Oil (Retrofit of an Existing Diesel Hydrotreater; See the Notes following the Table for How Certain Cost Inputs were Developed)

	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 BPSD (MMbbl/day)	25,000	25,000	25,000	31,200	31,200	31,200
Capital Cost (ISBL) (MM$)	16	18	19	5.5	7	15
LHSV (Liquid Hour Space Velocity (Hr^{-1})	2.5	1.5	1.2	1.5	0.9	0.7
Hydrogen Consumption (SCF/bbl)	125	185	198	95	147	160
Electricity (KwH/bbl)	0.24	0.36	0.37	0.5	0.6	0.6
Fuel Gas (BTU/bbl)	-1.5	-2.9	-3.0	100	100	100
Catalyst Cost ($/bbl)	0.06	0.08	0.1	0.14	0.41	0.51
Yield Loss (%) Diesel Naphtha LPG Fuel Gas	 -0.8 +0.5 +0.03 +0.05	 -1.0 +0.71 +0.04 +0.07	 -1.3 +0.88 +0.05 +0.08	Used Vendor A's Information	Used Vendor A's Information	Used Vendor A's Information

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.D-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. Based on the second capital cost which we generated, we estimated an alternate per-gallon cost in Chapter IX for the 25 ppm cap/15 ppm average standard which incorporates the second possible capital cost for Vendor B.

Since vendor A and B did not estimate the LHSV for a retrofit unit down to 5 ppm, we applied the ratio of the LHSVs provided by Vendor A for achieving 5 ppm to that for achieving 10 ppm for grassroots units, 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 13 SCF/bbl higher than that for achieving 10 ppm. Since Vendor B did not provide a estimate for achieving 7 ppm, we applied Vendor A's increased hydrogen consumption to Vendor B.

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 both Vendor A and B is estimated using the inverse ratio of the LHSVs for 7 ppm to the LHSV for 10 ppm provided by Vendor A.

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.

Table V.D-7. Process Operations Information for a Diesel Desulfurization Process Treating Diesel Fuel with No Light Cycle Oil (Retrofit of an Existing Diesel Hydrotreater; See the Notes following the Table for a Description How Certain Cost Inputs were Developed)

	Vendor A 50 ppm 800 psi Hydrotreating	*Vendor A 10 ppm 800 psi Hydrotreating*	*Vendor A 7 ppm 800 psi Hydrotreating*	*Vendor B 30 ppm 650 psi Hydrotreating*	*Vendor B 10 ppm 650 psi Hydrotreating*	*Vendor B 7 ppm 650 psi Hydrotreating*
Capacity BPSD (MMbbl/day)	25,000	25,000	25,000	31,200	31,200	31,200
Capital Cost (ISBL) (MM$)	15	17	18	5.5	6.2	7
LHSV Liquid Hour Space Velocity (Hr^{-1})	2.8	1.9	1.5	1.7	1.1	0.9
Hydrogen Consumption (SCF/bbl)	92	135	148	75	105	118
Electricity (KwH/bbl)	0.28	0.35	0.35	0.5	0.6	0.6
Fuel Gas (BTU/bbl)	-1.5	-2.9	-3.0	100	100	100
Catalyst Cost ($/bbl)	0.03	0.05	0.07	0.11	0.33	0.41
Yield Loss (%) 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	Used Vendor A's Information	Used Vendor A's Information	Used Vendor A's Information

When available, the information contained in Table V.D-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 no LCO 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 no LCO 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.D-6. above, the capital cost for treating diesel fuel with 23 percent LCO 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 only be $1 million more than for 10 ppm sulfur, as was the case for Vendor A. This assumption seemed reasonable since Vendor B's capital costs changed in small increments for reducing diesel sulfur with 23 percent LCO above 10 ppm, and treating a no LCO feed would enable meeting lower sulfur targets with the same capital investment.

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. Hydrogen consumption for both vendors' retrofit units treating no LCO were estimated in the same fashion.

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. 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.

Since the diesel sulfur standard is a cap standard, we are taking into account additional diesel desulfurization costs that would be incurred due to the cap standard. There are four aspects to this cost additional cost analysis. First, 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.[40] 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).[i] 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.

We believe that refineries with hydrocrackers will have to invest some money to ensure that recombinations reactions at the exit of their second stage hydrocracker does not cause their diesel fuel to cause 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.[41] [42] Thus, we assume that refiners will need to install a finishing reactor for the diesel stream produced by the hydrocracker. 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 0.2 c/gal to the cost of desulfurizing diesel fuel for those typical refineries with distillate hydrocrackers. The cost inputs for the storage tank and the finishing reactor are summarized in Table V.D-8.

[i] 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.D-8. 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$)	0.75	0.6
Electricity (KwH/bbl	---	0.98
HP Steam (Lb/bbl)	---	4.2
Fuel Gas (BTU/bbl)	---	18
Cooling Water (Gal/bbl)	---	5
Operating Cost ($/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.

** Denotes the capacity of the hydrocracker, but the capital is for treating the distillate stream only.

The problems associated with contamination of the highway diesel pool would increase as the diesel standard decreases. This is particularly an important problem with the heat exchangers which heats the feed to the diesel desulfurization unit using the product from that unit. 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 are expected to take preventative measures against contamination by welding the heat exchanger tubes to the plates, or by replacing their heat exchangers altogether.[43] To account for this added cost we assumed that each refinery would invest a million dollars for heat exchanger repair or replacement to achieve sulfur levels of near 10 ppm or below.[44]

Refiners will also likely invest in a diesel fuel sulfur analyzer.[45] 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.[46] 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 Factors

Capital costs are the one-time costs incurred by purchasing and installing new hardware in refineries. Capital costs for a particular processing unit were supplied by the vendors for a particular volumetric capacity and desulfurization efficiency based on 1999 dollars. These costs are adjusted to match the volume of the particular case being analyzed using the sixth tenths rule.[j] According to this rule, 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 the 0.6 power. 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, 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.[47] 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 then we volume-weighted each PADD value here to develop national average adjustment factors. 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 this program which is a revamp of an existing unit.[48] For estimating the cost to small refineries, we applied the offsite factor for small refineries, which is the same as that shown for PADD 4. The PADD-specific and national average cost factors are summarized in Table V.D-9 below.

[j] The capital cost is estimated at this other throughput using an exponential equation termed the "six-tenths rule." The equation is as follows: $(Sb/Sa)^e x Ca=Cb$, 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.D-9. Offsite and Location Factors Used for Estimating Capital Costs

	PADD 1	*PADD 2*	*PADD 3*	*PADD 4*	*PADD 5*	*National Average*
Offsite Factor - New Unit	1.25	1.25	1.20	1.50	1.30	1.24
- Revamped Unit	1.13	1.13	1.10	1.25	1.15	1.12
Location Factor	1.5	1.3	1	1.4	1.2	1.17

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.[49] The economic assumptions used to amortize capital costs over the production volume of low sulfur highway diesel fuel are summarized below in Table V.D-10.[50] 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.[k]

Table V.D-10. 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 Cost Factors

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,

[k] 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.

buildings costs for the control room and any support staff, supplies stored such as catalyst, and insurance.

Maintenance costs are estimated to be four percent of final capital costs and was taken from the Oak Ridge National Laboratory (ORNL) refinery model. Other fixed operating costs are also taken from the ORNL refinery model: three percent of capital costs for buildings, 0.2 percent for land, one percent for supplies which must be inventoried such as catalyst, and two percent for insurance. These other fixed operating cost factors sum to 6.2 percent and, when combined with the 4 percent maintenance cost factor, sum to 10.2 percent. This total fixed cost factor of 10.2 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 ORNL refinery model. Labor cost is very small, on the order of one thousandth of a cent per gallon.

iii. Variable Operating Cost

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 from our refinery model are initially from 1997 Energy Information Administration (EIA) information for various Petroleum Administrative Districts for Defense (PADDs) which are weighted together using the volumes of highway diesel produce in each PADD to derive a national average cost factor. We have information for 1997 because we gathered it for the Tier 2 rule. We adjusted the 1997 cost factors to represent the prices in the year 2006 based on $1999 using retail price projections, minus taxes, by EIA for gasoline and diesel fuel. This adjustment amounted to about three percent, so we used three percent.[51] To estimate the steam cost, we initially estimate the cost based on the cost of the fuel gas consumed and then increase the cost by a factor of two which is consistent with published cost estimation methodology.[52] 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 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 to the resale price for diesel fuel from EIA. Similarly, the estimated cost of Tier 2 low sulfur gasoline, which is about 2 c/gal, is added to the price of gasoline used in the yield loss calculation. These cost factors are summarized in Table V.D-11.

Table V.D-11. Summary of Costs Taken From EIA Information Tables *

	National Cost Factors
Electricity (c/KwH)	4.5
LPG ($/Bbl)	18.2
Diesel ($/Bbl)	26.8
Gasoline ($/Bbl)	31.1
Fuel Gas ($/MMbtu)	4.4
Hydrogen Cost ($/MSCF)	2.4

* c/KwH is cents per kilowatt-hour, $/Bbl is dollars per barrel, $/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.[53] 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 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. This improved operations management could involve enhancements to the computer systems which control the refinery operations, as well as improved maintenance practices.[54] 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.[55] [56] No costs were included in the cost analysis for these potential issues.

d. Diesel Volumes for Characteristic Typical and Small Refineries for Deriving Aggregate Capital and Operating Costs

To better explain the impact of this program, we estimated the refinery capital and operating costs for characteristic typical and small refineries for estimating the costs to those refineries, and then developed aggregate capital and operating costs for the entire U.S. refining industry. Typical and small refineries are defined based on the volumes of highway diesel fuel currently being produced as shown in Table V.D-12. For projecting the aggregate capital and operating costs (including the cost to foreign refiners importing highway diesel fuel to the U.S.), we used the projected national highway diesel fuel consumption for 2006 developed by EIA. These projected values are also summarized below in Table V.D-12.

Table V.D-12. Projected 2006 Aggregate U.S. Highway Diesel Fuel Consumption, and Average and Small Refinery Low Sulfur Highway Diesel Fuel Production Volumes

Low Sulfur Diesel Fuel Production Volume Per Average Refinery (Bbl/day)	19,240
Low Sulfur Diesel Fuel Production Volume Per Small Refinery (Bbl/day)	9000
Total Projected Low Sulfur Diesel Consumption in 2006 (Million Gallons/yr)	39,500

EPA estimated the size of the average refinery (which produces highway diesel fuel) by dividing projected future highway diesel fuel production by domestic refineries by the number of domestic refineries currently producing highway diesel fuel. Future highway diesel fuel production by domestic refineries was estimated by subtracting projected imports of highway diesel fuel from total U.S. consumption. Both figures were taken from the EIA 2000 Annual Energy Outlook. For 2006, total highway diesel fuel consumption is projected to be 39.5 billion gallons per year, with imports of 2.0 billion gallons per year. Currently, 127 refineries produce highway diesel fuel. Assuming the same number of refineries produce highway diesel fuel in 2006, the average domestic refinery is projected to produce 295 million gallons per year of highway diesel fuel, which is equivalent to 19,200 barrels per day. This is a 12.6 percent increase from the average production of 17,100 barrels per day in 1998. The average sized refinery highway diesel fuel production is used for calculating the aggregate refinery capital and operating costs reported below.

Because the capital cost of refining equipment is not proportional to the size of the equipment, the average capital cost per refinery is not the same as the capital cost projected for the average-sized refinery. We provide an example here to demonstrate this issue. We will choose two refineries, "Refinery 1" which produces 10,000 bpd of highway diesel fuel (among other products in about a 50,000 barrel of crude oil per day refinery), and "Refinery 2" which produces 40,000 bpd highway diesel fuel (among other products in about a 200,000 barrel of crude oil per day refinery). If we use the capital cost inputs for Vendor A to calculate the per-gallon capital cost of each refinery in the example, we determine the per-gallon capital cost to be 1.2 c/gal for Refinery 1, and 0.706 c/gal for Refinery 2. Volume weighting these two costs together yields a per-gallon capital cost of 0.804 c/gal. If we average the barrels per day highway diesel fuel production capacity of these two refineries, we find that they average to 25,000 bpd. However, if we estimate the per-gallon capital cost for a 25,000 per day refinery using Vendor A's cost inputs, we find the cost calculates to be 0.842 c/gal, a significantly higher cost. After inputting different highway diesel fuel capacities into our refinery cost model using trial and error, we determine that a 28,000 bpd diesel desulfurization unit would give the same per-gallon capital cost as the volume weighted cost of our two example refineries.

To correct for this non-linear relationship in our cost study, we evaluated the variability in individual refineries highway diesel fuel production and its effect on capital costs using refinery production data. First, we returned to the EIA data described above which describes each refinery's highway diesel fuel production from the last half of 1998 and the first half of 1999. These records covered 117 refineries producing at least 500 barrels per day of highway diesel fuel. We then estimated the relative capital cost of a diesel hydrotreater for each of these refineries assuming a hypothetical capital cost of $30 million for a base production volume of 20,000 barrels per day. This was done using the following equation:

$$\text{Cost for Volume A} = \text{Cost for Base Volume} * (\text{Volume A} / \text{Base Volume})^{a}$$

This equation reflects the fact that the cost of a diesel hydrotreater varies less than proportionally to its volume. For diesel hydrotreaters, a is 0.65. This means that doubling the size of a diesel fuel hydrotreater only increases the capital cost of the hydrotreater by 57%.

The sum of the capital costs for all 117 refineries was $3.1 billion. The average capital cost per refinery was $26.8 million. The average capital cost per refinery per barrel per day of production was $1354 per barrel per day. We then divided both sides of the above equation by the production volume of refiner A to produce the following equation:

$$\text{Cost per volume of production} = \frac{\text{Cost for Base Volume}}{\text{Volume A}^{0.35} * \text{Base Volume}^{0.65}}$$

By setting the cost per volume of production to $1354 per barrel per day, and setting the base volume and cost to 20,000 barrels per day and $30 million, respectively, we determined the average volume (Volume A) to be 26,700 barrels per day in 1998. This means that one can determine the capital cost per volume of diesel fuel production using 26,700 barrels per day and apply it to total diesel fuel production and produce the same capital cost as if one summed the capital cost for each of the 117 refineries using its specific production volume. Finally, applying the 12.6 percent growth in production to 2006 yields a production volume for capital cost estimation of 30,200 barrels per day. We used this production volume in our refinery model for estimating the per-gallon cost of desulfurizing diesel fuel.

The small refinery production volume of 9000 barrels per calendar day is determined in a different fashion. Since we are primarily concerned with the difference in the per-gallon highway diesel fuel production cost between these refineries and the typical refinery to better understand the challenge to these refineries, we only averaged the volumetric production of this group. However, we first removed the refineries producing less than 500 barrels per day since they would likely not put in a desulfurization unit for such a small highway diesel fuel production volume. We increased the volumetric production of these refineries using the 12.6 percent growth to 2006 to yield 9000 barrels per day.

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 and this would not change under our proposal.[1] Thus, our cost projections include hydrotreating that volume of 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 proposed 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. Cost of Desulfurizing Highway Diesel Fuel

a. EPA Costs

The capital and operating cost inputs described above were combined together in our refinery model to estimate the cost of desulfurizing highway diesel fuel from the base sulfur level of 340 ppm to an average of 7 ppm sulfur to meet the 15 ppm cap standard. These costs were developed for a typical U.S. refinery, and an average-sized small refinery.

[1] 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.

The per-refinery capital and operating costs, and the per-gallon cost for these two typical refineries is summarized in Table V.D-13 below.

Table V.D-13. Estimated Per-Refinery Capital, Operating and Per-Gallon Cost of Desulfurizing Highway Diesel Fuel to Meet a 15 ppm Cap Standard (1999 Dollars)

	Refineries which Average 23 Percent LCO in Diesel Fuel	*Refineries with No LCO in their Diesel Fuel*
Typical Sized Refinery		
Capital Cost ($Million)	31	23
Operating Cost ($Million/yr)	8.3	6.6
Per-Gallon Cost (c/gal)	4.0	3.1
Small Refiner		-
Capital Cost ($Million)	22.8	-
Operating Cost ($Million/yr)	4.9	-
Per-Gallon Cost (c/gal)	5.4	-

Table V.D-13 shows that, on average, typical refineries which process 23 percent LCO would incur a capital cost of $31 million to meet the proposed sulfur cap. In addition, typical refineries would incur an average of $8 million per year in operating costs. The capital and operating cost for typical small refineries would be much lower, $23 million and $5 million per year per refinery, respectively, but due to their lower production volumes, their costs would be higher on a per-gallon basis.

Regarding the sensitivity case of refineries treating diesel fuel with no LCO, the estimated costs to the refineries which must treat diesel fuel with LCO are about 25 percent higher than the costs of those refineries without LCO in their diesel fuel. Also, the per-gallon cost to the refineries which must treat LCO is about 25 percent higher than the cost to refineries which treat no LCO. Conversely, the per-gallon cost to a characteristic small refinery is about 30 percent higher (about 1½ cents per gallon) than the per-gallon cost of a typical-sized refinery, thus, our analysis projects that small refineries are more challenged than the refineries which treat a large portion of their diesel fuel as LCO.

These costs are estimated based on a typical refinery and do not reflect the diversity of costs expected from a very diverse industry. Refineries vary by feed type, size or capacity, configuration, and product mix which can vary seasonally, all of which affects the costs. Our goal here is to estimate the average cost for the industry as a whole, not to capture the cost or the cost range to individual refineries.

The aggregate operating and capital costs for the U.S. refining industry were developed for 2006-2035. To calculate the aggregate capital cost, the total capital cost per refinery which we estimated in our refinery model was simply multiplied times the 127 refineries in the U.S. which produce highway diesel fuel. We then calculated the yearly operating costs based on the projected diesel consumption in 2007 shown in Table V.D-12. The per-gallon operating cost is calculated by simply multiplying the per-gallon cost and the volumetric consumption together. Capital costs which are estimated to total $4.1 billion are presumed to be incurred in 2004, 2005 and 2006 as the desulfurization units are installed in the refinery. A second round of capital cost investments is assumed to occur 15 years later as the desulfurization units installed during 2004, 2005 and 2006 reach the end of their useful life. Aggregate capital costs increase in 2020 - 2022 relative to 2004 - 2006 due to increased fuel production volumes. The aggregate operating costs increase each year due to the constant increase in growth in diesel demand. These costs are summarized in Table V.D-14.

Table V.D-14. Projected U.S. Aggregate Operating and Capital Cost of Desulfurizing Highway Diesel Fuel to Meet a 15 ppm Cap Standard (1999 Dollars)

Year	*Projected 7 ppm Diesel Fuel Consumption (Billion Gals)*	*Projected Aggregate Operating Cost ($Billion)*	*Projected Aggregate Capital Cost ($Billion) **	*Projected Total Aggregate Cost ($Billion)*
2004	-		1.9	1.9
2005	-		2.0	2.0
2006	39.5*0.75	0.83	0.2	1.03
2007	40.1	1.13	-	1.13
2008	40.7	1.14	-	1.14
2009	41.3	1.16	-	1.16
2010	41.9	1.18	-	1.18
2011	42.6	1.20	-	1.20
2012	43.2	1.22	-	1.22
2013	43.8	1.24	-	1.24
2014	44.5	1.26	-	1.26
2015	45.2	1.28	-	1.28
2016	45.8	1.29	-	1.29
2017	46.5	1.31	-	1.31
2018	47.2	1.33	-	1.33
2019	47.9	1.35	2.2	3.55
2020	48.7	1.38	2.3	3.68
2021	49.4	1.40	0.2	1.60
2022	50.1	1.42	-	1.27
2023	50.9	1.44	-	1.44
2024	51.6	1.46	-	1.46
2025	52.4	1.48	-	1.48
2026	53.2	1.50	-	1.50
2027	54.0	1.52	-	1.52
2028	54.8	1.55	-	1.55
2029	55.6	1.57	-	1.57
2030	56.5	1.59	-	1.59
2031	57.3	1.62	-	1.62
2032	58.2	1.64	-	1.64
2033	59.1	1.67	-	1.67
2034	59.9	1.69	-	1.69
2035	60.8	1.71	-	1.71

* For U.S. refiners only.

Table V.D-14 shows that the aggregate capital cost for complying with the proposed 15 ppm highway diesel sulfur cap is expected to initially total about $4.1 billion spread out a little more than two years. This level of capital expenditure is less than the capital expenditures expected to be made by the U.S. refining industry for complying with gasoline sulfur standards. Also, during the early nineties the U.S. refining industry invested over six billion dollars in capital for environmental controls for their refining operations; this cost represented about one third of the total capital expenditures made by refiners for their refineries. Considering the effects of inflation and that these expenses were incurred by less than three quarters of the refining industry,[m] we believe that a program requiring the refining industry to spend about $4.1 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.D-15 below, projected costs per gallon of complying with the proposed sulfur cap for the average refinery and a small refinery are shown using a variety of rates of return on investment (ROI) before taxes. The first costs shown are our estimates of the costs to society, which utilize a seven percent ROI. Following those costs, we then present two sets of cost estimates, which use six and ten percent ROIs, respectively. These latter rates of return are indicative of the economic performance of the refining industry over the past 10-15 years.

Table V.D-15. Per-Gallon Cost for Average and Small Refineries to Desulfurize Highway Diesel Fuel to Meet a 15 ppm Cap Standard Based on Different Capital Amortization Rates
(1999 Dollars)

	Average Refinery Cost (c/gal)	*Small Refiner Cost * (c/gal)*
Societal Cost 7% ROI before Taxes	4.0	5.4
Capital Payback (6% ROI, after Taxes)	4.0	5.5
Capital Payback (10% ROI, after Taxes)	4.3	6.1

b. Uncertainty in the Estimated Cost to Desulfurize Diesel Fuel

A couple of potential sources of uncertainty in the projected cost of desulfurizing diesel fuel exist in addition to those which have already been discussed above. According to participants of the

[m] This capital cost estimate was made only for the major oil companies.

current NPC study, vendors of refinery processing units typically underestimate their capital costs and utility demands for their refining processes, presumably for marketing reasons. Thus, the NPC Draft Study advocates the use of adjustment factors for the capital and operating costs, which are 1.2 and 1.15, respectively. Our adjustment factors are slightly lower than those used by those NPC members (1.15 for capital and 1.1 for operating costs), however, our factors also are meant to account for other minor costs incurred in the refinery which we don't estimate directly. However, we question the need for a more significant adjustments to the vendor estimates. Even if vendors costs were underestimated now, between now and when this program would begin these same vendors will be making improvements in their desulfurization technology. Improvements in catalyst technology will enable incremental reductions in the capital costs, at least up to two years before the program goes into effect, and incremental reductions in operating cost will be realized throughout the life of the desulfurization unit. Also refiners may be able to use existing spare equipment or vessels in their refinery for parts of the desulfurization revamp. While these pieces of equipment or vessels only impact a portion of the overall capital cost, since this spare equipment must be still mounted, piped up and instrumented, there is a cost reducing impact which is important to recognize.

There are also operational changes which refiners can make to reduce their desulfurization cost. Based on our cost analysis, 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 proposed sulfur cap. 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.[57] 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.

To the extent that diesel desulfurization vendors continue to improve their desulfurization technology, or that refiners can use existing spare equipment or resort to either of these two operational options to reduce the amount of LCO in their highway diesel fuel provides an offsetting effect to any cost underestimation which may be a practice by the diesel desulfurization vendors. Thus, while our desulfurization costs could be higher than what we are reporting, they could be lower as well.

If we consider the possibility of an emerging technology, the cost of desulfurizing diesel fuel could be much lower than what we have estimated. Energy BioSystems 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.[58] 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.[59] Both of these processes are still being developed, though, and may not be ready in time for the implementation date of this proposed rule.

c. Comparison with Engine Manufactures Association Cost Estimate

Our estimate for the cost of desulfurizing diesel fuel compares favorably with an estimate by MathPro, Inc. in a study conducted for the Engine Manufacturers Association[60]. This study analyzed a number of cases for both highway and non-road diesel sulfur reductions assuming that gasoline sulfur control has already been implemented. MathPro assumed that desulfurization would occur entirely through severe conventional hydrotreating, and refinery operations were modeled using the 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 represent PADDs 1, 2, and 3.

Of the ten desulfurization scenarios modeled by MathPro, none of them line up directly with EPA's proposal. Nevertheless, by interpolating from the scenarios MathPro did analyze, we can come up with a reasonable estimate of what MathPro's costs would have been had they analyzed the same scenario. The most directly applicable scenarios of Mathpro were their case 1, where the reduced the sulfur concentration of highway diesel fuel to an average of 20 ppm, and their MP1 scenario where they reduced it to an average of 2 ppm. By interpolating between these two cases to an average production level of 7 ppm corresponding to a cap of 15 ppm, the Mathpro study would project a cost of 4.5 to 6.2 cents per gallon. Some of the assumptions made by MathPro in their cost estimate were different than those used by EPA and would need to be adjusted for to allow for a fair comparison with EPA's cost estimates. Unfortunately, it is difficult with the information available to fully adjust for all these differences. Nevertheless, we believe that were we to do so, the MathPro cost estimates would still compare favorably with our own.

Some of the adjustments that would need to be made include the following. First, our costs are calculated based on a 7 percent rate of return on investment (ROI) before taxes, while the MathPro costs are based on a 10 percent ROI after taxes. Second, the MathPro estimates for cases 1 and MP1 also include costs for desulfurizing off-highway diesel fuel down to 350 ppm. 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, the magnitude of the adjustment in the MathPro study was presumably heavily impacted by the inclusion of off-highway sulfur control as well. Furthermore, some of the reblending costs in the MathPro study appear to be transfer payments[n], not costs. Fourth, MathPro assumed that all new hydrogen demand is met with new hydrogen plants installed in the refinery, which does not take any advantage of hydrogen purchased from a third party which can produce it 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 MathPro study did take into consideration the need for lubricity additives, but did not address costs that might be incurred in the distribution system. Consequently, these adjustments must be taken into consideration when comparing the MathPro and EPA cost estimates.

3. The added cost of Distributing Low-Sulfur Fuel

Under the proposed 15 ppm sulfur cap, we estimate that distribution costs would increase by a total of 0.2 cents per gallon as discussed below.

[n] A transfer payment is when a cost is not incurred, but instead a product is sold between two entities. In this case, Mathpro was considering the sale of an untreated blendstock from one refinery to another as a cost.

We identified two segments in the distribution system (pipeline operators and terminal operators) that would experience increased costs due to increased difficulty in limiting sulfur contamination under the proposed sulfur standard (see Section IV.D.). As discussed below, we estimate that the total increase in diesel distribution costs associated with adequately limiting sulfur contamination under today's proposal would be no more than 0.1 cents per gallon for the distribution system as a whole. The majority of this increased cost is attributed to limiting mixing of highway diesel with other products in the pipeline. Only a small fraction is attributed to the need for increased quality assurance testing at the terminal level.

The need to distribute a larger volume of diesel fuel to meet the same level of consumer demand would also increase distribution costs. This need is a consequence of the reduction in the energy density of diesel fuel which occurs as a side effect of reducing sulfur content to the proposed 15 ppm cap. The cost of distributing the increased volume of diesel fuel was calculated within the context of evaluating diesel fuel desulfurization costs (see V.D.1). Spread over the total volume of highway diesel fuel distributed, the additional cost is estimated at 0.1 cents per gallon.

We also recognized that the pool from which kerosene is drawn for winter time blending with highway diesel fuel would need to be desulfurized to a level comparable with the proposed highway diesel fuel sulfur standard (see Section IV.D.). The cost of desulfurizing this kerosene pool is incorporated into EPA's estimated costs of desulfurizing highway diesel fuel (See Section V.D.2).

We believe that although some tank-truck operators may need to more carefully observe current industry practices used to limit product contamination. As discussed in Chapter 4, these practices include making sure that the tank-truck is properly leveled when draining high-sulfur product prior to filling with the proposed diesel fuel, allowing sufficient time for the tank to drain completely, and purging delivery lines of high-sulfur product prior to a delivery of the proposed fuel. Since these are currently standard industry practices, EPA does not anticipate that there would be increased costs associated with their observance. However, some marketers may need to stress to their employees the importance of carefully and consistently observing these practices. To the extent that such employee education is needed at all, we anticipate that it might be accomplished in regular employee meetings or employee bulletins at negligible cost. If additional information should become available through the comment process on the NPRM, we may attempt to quantify the potential cost to diesel distributors of maintaining careful observation of current industry practices.

As discussed in Section IV.B., two potential areas where costs might increase for pipeline and terminal operators were identified (pipeline interface and terminal quality assurance testing). Since the amount of interface required to prevent sulfur contamination of highway diesel is largely determined by the difference in sulfur content with adjacent products in the pipeline, the amount of interface required to prevent sulfur contamination during pipeline shipments of highway diesel would increase if the proposed sulfur standard is implemented. One industry representative estimated that a typical interface volume would increase anywhere from 300 barrels to 1,200 barrels on each end of a shipment of highway diesel fuel, for a total increase in the interface volume per pipeline shipment of highway diesel in the range of 600 to 2,400 barrels. Based on this estimate, interface volumes for pipeline shipments of on highway diesel fuel would increase by 25 - 33 percent. The price penalty for selling the interface as off-highway diesel fuel varies according to local market conditions. For the purposes of this analysis, we are assuming an average 5.6 cents[o] per gallon price penalty. Using these figures, the additional cost penalty of selling the interface as off-highway diesel fuel was estimated to range from approximately $1,400 to $5,600 per pipeline batch. The amount of interface is independent of the size of the batch. Pipeline batch sizes vary widely. For example, the minimum batch on the Colonial Pipeline is 75,000 barrels. Based on an average batch size of 100,000 barrels, the increase in the cost of shipping highway diesel by pipeline was estimated to be below 0.1 cents per gallon.

For the purposes of this analysis, it was assumed that all on highway diesel fuel was assumed to travel by pipeline. Therefore, the increased costs of shipment by pipeline was assessed on all highway diesel fuel. Since it is likely that not all on highway diesel travels by pipeline, this approach provides a worst case cost estimate.

The second area where costs might increase is quality assurance testing by terminal operators. We estimate the cost of such additional quality assurance measures to be $100 for each batch. This estimate includes the cost of sampling and testing each batch for its sulfur content. Consequently, for an average batch of 100,000 barrels, the cost increase would be approximately 0.002 cent per gallon. Adding this cost to that estimated above for the increase in interface volumes, we estimate that the total increase in distribution costs from the proposed diesel sulfur standard and associated requirements would be 0.1 cents per gallon. There could be an increase in the occurrence of noncomplying fuel showing up in the distribution system, which would either have to be brought up to specification, downgraded to off-highway, or re-refined, though we have assumed that the frequency of such occurrence would be low enough as to not impact the costs of the program noticeably.

4. What is the Projected Cost of Lubricity Additives?

Adoption of the proposed 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)[61], sponsored by the Engine Manufacturers Association to estimate the costs of diesel fuel desulfurization under sulfur standards that we were likely to

[o] The 5.6 cents/gallon cost of downgrading on highway diesel fuel interface volumes to off highway fuel was derived by adding the estimated increase in the cost of producing highway diesel fuel which meets the proposed requirements (4 cents / gallon) to the current price differential observed between the price of on highway and off highway diesel fuel (1.6 cents / gallon).

propose, 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 IV.D.4-1).

Table V.D.4-1 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 our proposed 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 proposed 15 ppm cap sulfur standard. Of the cases evaluated by MathPro, we believe its highway/off-highway 20 ppm average scenario most closely matches our proposed 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 proposed 15 ppm sulfur cap standard would be in the range of 0.2 cents per gallon.

5. Per-Engine Life-Cycle Fuel Costs

The additional cost of low sulfur diesel meeting our proposed 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.

The total cost of low sulfur diesel is the sum of refinery desulfurization costs, addition of a lubricity additive, and increases in distribution costs with respect to that incurred by baseline fuel meeting the current 500 ppm sulfur cap. Refinery desulfurization and distribution costs are discussed earlier in this Chapter, and average 4.0 ¢/gal and 0.2 ¢/gal respectively in the first year of the program. Lubricity additives are discussed in Section V.C.4, and average 0.2 ¢/gal. Thus we estimate the total cost of low sulfur diesel fuel meeting our proposed 15 ppm cap to be 4.4 ¢/gal.

In a single year, the average in-use heavy-duty engine travels approximately 30,000 miles[p], though the mileage of any given engine varies by usage, age, and other factors. Applying the average heavy-duty fuel economy, the cost for low sulfur fuel of 4.4 ¢/gal leads us to a per-engine estimate of approximately $182. This is the additional cost that the average engine owner will incur in the first year of the sulfur program due to the use of low sulfur diesel, if the full social costs of meeting the proposed sulfur cap 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.

The per-engine cost of low sulfur diesel 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 low sulfur diesel 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

[p] 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.

$(AVMT)_i$ = Annual engine miles travelled in year i of a engine's operational life[62]
$(SURVIVE)_i$ = Fraction of engines still operating after i years of service[63]
C = Cost of low sulfur diesel, starting at $0.044/gal
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.D.5-1 as "undiscounted lifetime costs."

An alternative approach to calculating lifetime per-engine costs of low sulfur diesel 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.D.5-1 as "discounted lifetime costs."

Table V.D.5-1. Fleet Average Per-Engine Costs Of Low Sulfur Diesel ($)

	LH	*MH*	*HH*	*UB*	*All*
First year	57.08	107.73	381.78	418.00	182.48
Undiscounted lifetime, near-term	736.78	1377.61	4975.61	6713.83	2378.92
Undiscounted lifetime, long-term	736.78	1377.61	4975.61	6713.83	2378.92
Discounted lifetime, near-term	536.25	1003.70	3704.08	4363.86	1753.91
Discounted lifetime, long-term	536.25	1003.70	3704.08	4363.86	1753.91

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

E. Combined Total Annual Nationwide Costs

Figure V.E-1 and Table V.E-1 summarize EPA's estimates of total annual costs to the nation for heavy-duty diesel engines, heavy-duty gasoline vehicles, and low sulfur diesel. 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 low sulfur diesel fuel consumed nationwide, including that consumed in both highway and off-highway applications. Annual aggregate engine and vehicle 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 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 Sections A.7, B.6, and D.7 of this chapter. As shown below, total annual costs increase over the phase-in period and peak at about $3 billion in 2010. Total annualized costs are projected to increase gradually after 2010 due to projected growth in vehicle sales and fuel consumption.

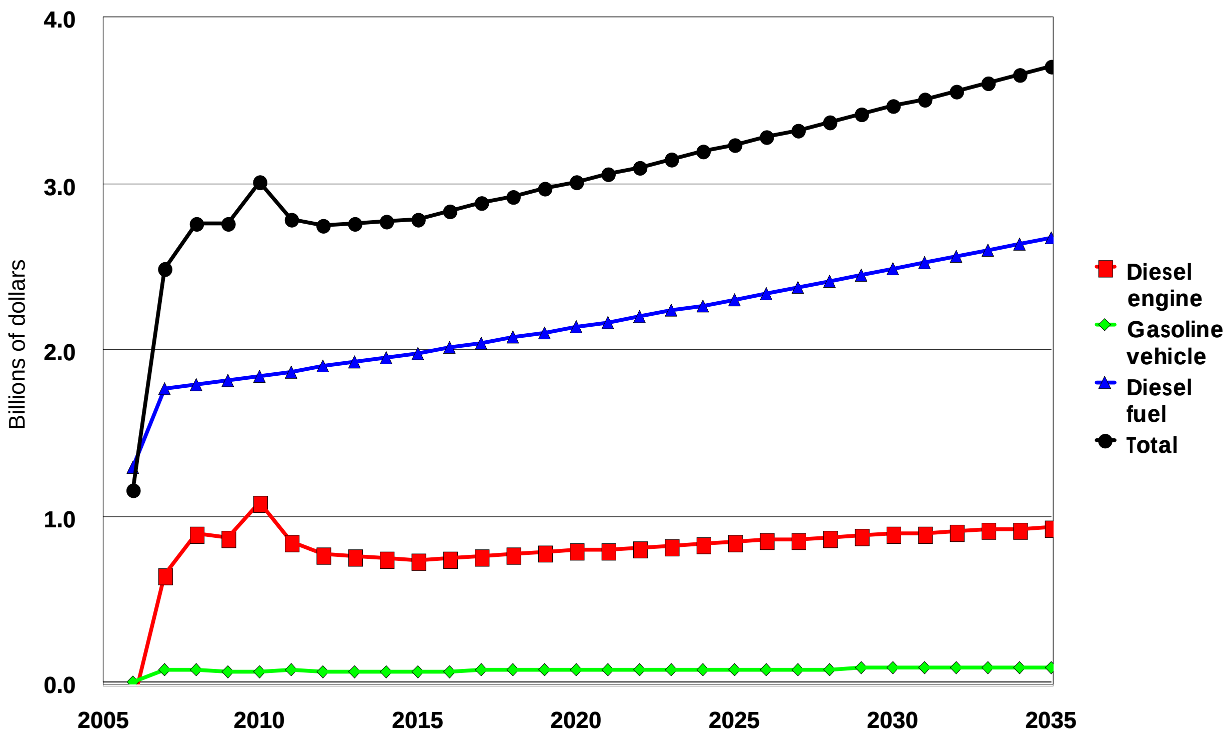

Figure V.E-1. Total annualized costs of heavy-duty diesel engines, heavy-duty gasoline vehicles, and low sulfur diesel.

Table V.E-1. Total annualized costs of heavy-duty diesel engines, heavy-duty gasoline vehicles, and low sulfur diesel. ($million)

	Diesel engines	*Gasoline vehicles*	*Diesel fuel*	*Total*
2006	(148)	0	1,304	1,156
2007	654	77	1,764	2,495
2008	904	79	1,791	2,773
2009	891	73	1,818	2,782
2010	1,107	74	1,845	3,026
2011	865	75	1,873	2,813
2012	799	70	1,901	2,770
2013	787	71	1,929	2,786
2014	773	72	1,958	2,803
2015	759	73	1,987	2,819
2016	774	74	2,017	2,865
2017	788	75	2,047	2,910
2018	802	76	2,078	2,956
2019	815	77	2,109	3,001
2020	828	78	2,141	3,047
2021	840	79	2,173	3,092
2022	852	80	2,206	3,138
2023	863	81	2,239	3,184
2024	874	82	2,272	3,229
2025	885	83	2,306	3,274
2026	896	84	2,341	3,321
2027	906	86	2,376	3,367
2028	916	87	2,412	3,415
2029	926	88	2,448	3,462
2030	936	89	2,485	3,509
2031	945	90	2,522	3,557
2032	955	91	2,560	3,606
2033	965	92	2,598	3,654
2034	974	93	2,637	3,704
2035	983	94	2,677	3,754

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