CHAPTER 6: Estimated Engine and Equipment Costs

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This chapter discusses the various engine and equipment cost elements considered for the proposed emission standards and presents the total engine and equipment related costs we have estimated for compliance with the proposed new standards. First, in Section 6.1, a brief outline of the methodology used to estimate the engine and equipment cost impacts is presented. Next, in Sections 6.2 and 6.3, the projected costs of the individual technologies expected to be used to comply with the proposed standards are presented, along with a discussion of fixed costs such as research and development (R&D), tooling, certification, and equipment redesign. Section 6.4 summarizes these costs and presents all engine, equipment, and operating costs in a concise format. Section 6.5 then presents cost estimates for several example pieces of equipment. A complete presentation of the aggregate cost of compliance for engines and equipment is presented in Chapter 8 of this Draft RIA.

Note that we do not present any sensitivity analysis here. An analysis of sensitivity is presented in Chapter 9 where we present monetized benefits and social costs. Note also that the costs presented here do not include potential savings associated with our engine ABT program or our Transition Program for Equipment Manufacturers, because these are voluntary programs that, while we fully expect industry to use them to reduce compliance costs, they are not required to do so; all compliance costs presented here are for proposed regulatory requirements. Unless noted otherwise, all costs presented here are in 2001 dollars.

6.1 Methodology for Estimating Engine and Equipment Costs

This analysis makes a number of simplifying assumptions regarding how manufacturers would comply with the proposed standards. First, in each horsepower category, we assume a single technology recipe as discussed in detail in Chapter 4 of this Draft RIA. However, we expect that each manufacturer would evaluate all possible technology avenues to determine the one or ones that best balance costs while ensuring compliance. In addition, we fully expect manufacturers to make use of both the averaging, banking, and trading (ABT) program for engine manufacturers and the transition program for equipment manufacturers (TPEM) as a way to deploy varying degrees of emission control technologies on different engines and equipment. As noted, for developing cost estimates, we have assumed that the industry does not use either the TPEM or ABT programs, both of which offer the opportunity for significant cost reductions. Given these simplifying assumptions, we believe that the cost projections presented here provide a conservative cost estimate that probably overestimates the costs of the different approaches toward compliance that manufacturers may ultimately take.

For smaller nonroad engines – those under 75 horsepower – many of the technologies we expect would be needed for compliance would be applied for the first time. Therefore, we have sought input from a large section of the regulated community regarding the future costs that would be incurred to apply these technologies to diesel engines. Under contract from EPA, ICF

Consulting provided questions to several engine and parts manufacturers regarding costs associated with emission control technologies for diesel engines. The responses to these questions were used as a first step toward estimating the costs for many of the technologies we believe would be required for compliance. These costs form the basis for our estimated costs for "traditional" engine technologies such as EGR and fuel injection systems.[1]

Costs for exhaust emission control devices (e.g., catalyzed diesel particulate filters (CDPF), NOx adsorbers, and diesel oxidation catalysts (DOC)) were estimated using the methodology used in our 2007 HD highway diesel rulemaking. In that rulemaking effort, ICF Consulting, under contract to EPA, provided surveys to nine engine manufacturers seeking their estimates of the costs for and types of emission control technologies that might be enabled with low sulfur diesel fuel. The survey responses were used as the first step in estimating the costs for advanced emission control technologies we expected would be applied in order to meet the proposed 2007 heavy-duty diesel highway standards.[2] These costs were then further refined by EPA based upon input from members of the Manufacturers of Emission Controls Association. Because the exhaust emission control technologies expected for compliance with the proposed nonroad standards are the same as expected for highway engines, and because the suppliers of the technologies are the same for nonroad engines as for highway engines, we are using that analysis as the basis for our cost estimates here.

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

EPA has also identified various factors that would cause cost impacts to decrease over time, making it appropriate to distinguish between near term and long term costs. Research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts.[5] This analysis incorporates the effects of this learning curve as described in Section 6.2.2 of this chapter.

Fixed costs for engine R&D are estimated to be incurred over the five-year period preceding introduction of the engine. Fixed costs for tooling and certification are estimated to be incurred one year ahead of initial production. Fixed costs for equipment R&D/redesign are estimated to be incurred over a two year period preceding introduction of the piece of equipment, while equipment tooling costs are estimated to be incurred one year ahead of initial production. All fixed costs are increased by seven percent for every year before the start of production. Engine fixed costs are then "recovered" with a five-year amortization at the same rate except where a phase-in of a new standard occurs in which case the fixed costs are recovered during the phase-in years and then during the five years following 100 percent compliance.[A] Equipment fixed costs are recovered with a 10-year amortization at the same seven percent rate; the longer amortization period for equipment fixed costs reflects the longer product cycle for equipment. We have also included lifetime operating costs where applicable. These include costs associated with the higher cost fuel, potential fuel economy impacts, increased maintenance demands resulting from the addition of new emission control hardware, and expected savings associated with lower oil change maintenance costs as a result of the low sulfur fuel.

A simplistic overview of the methodology used to estimate engine and equipment costs would be as follows:

- For fixed costs (i.e., R&D, redesign, tooling, certification), we estimate the total dollars that industry will spend. We then calculate the total dollars that they will recover in each year of the program following implementation. These annual costs of recovery represent our estimate of fixed costs associated with the proposal. In Section 6.5 and in some engine-related fixed cost tables in Section 6.2.1, we also present an estimate of per-unit fixed costs. These per-unit fixed costs are impacted by the way we have broken up the horsepower categories in this cost analysis and by other factors (e.g., the engine prices we have estimated) as discussed in more detail below. Because we do not know how manufacturers would actually recover their costs on a per-unit basis, we present these per-unit fixed costs for informational purposes only. We do not use these per-unit fixed cost estimates in our cost per ton calculations; instead, we use the annual cost of recovery totals in the aggregate cost per ton calculations presented in Chapter 8 of this Draft RIA.

- For engine variable costs (i.e., emission control and associated hardware), we first estimate the cost per piece of technology. As described in detail in Section 6.2.2, emission control hardware costs tend to be directly related to engine characteristics – e.g., exhaust emission control devices are sized according to engine displacement so that costs vary by displacement; fuel injection systems vary in cost according to how many fuel injectors are required so that costs vary by number of cylinders. Therefore, we are able to determine a variable cost equation as a function of engine displacement or as a function of the number of

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[A] We have estimated a "recovered" cost for all engine and equipment fixed costs to present a per unit analysis of the cost of the proposal. In general, in environmental economics, it would be more conventional to simply count the total cost of the program (i.e., opportunity costs) in the year they occur. However, this approach would not directly estimate a per unit cost since fixed costs occur prior to implementation of the standards and, therefore, there are not yet any units certified as complying with the new standards to which the fixed costs can be attributed. As a result, we grow fixed costs until they can be "recovered" on complying units. Note that the approach used here results in a higher estimate of the total costs of the program since the recovered costs include a seven percent rate of return to the manufacturer.

cylinders. We then consider each unique engine's baseline technology package using a database of all nonroad equipment sold in the United States (U.S.).[6] That database lists engine characteristics for every one of over 7,000 pieces of equipment sold in the US and provides the sales of each piece of equipment. Using the current engine characteristics of each engine, the projected technology package for that engine, and the variable cost equations described in section 6.2, we calculate a variable cost for the engine in each of the over 7,000 pieces of equipment sold in the US. This variable cost per engine is then multiplied by that engine's projected sales in each year for the years following implementation of the new standards. We then total the annual costs for all engines to get the fleetwide variable costs per year. These fleetwide variable costs per year are then used in the cost per ton calculations presented in Chapter 8 of this draft RIA.

- Note that the cost per ton calculation is never impacted by how many horsepower categories we use in our cost analysis. We sometimes break up the fleet into more horsepower categories than would seem reasonable given the structure of the proposed standards. We do this for a couple of reasons: (1) phase-ins of standards and/or different levels of baseline versus proposed standards sometimes force such breakouts; and, (2) greater stratification (i.e., breaking up the 75 to 175 horsepower range and the 175 to 750 horsepower range) provides a better picture for use in our estimate of potential recovery of fixed costs. Importantly, the number of horsepower categories used does not impact the total costs estimated as a result of the proposed standards, and these total costs are the costs used to calculate a cost per ton number.

Engine costs are presented first – fixed costs, variable costs, then operating costs. Equipment costs follow – fixed costs then variable costs. A summation of engine and equipment costs follows these discussions. Variable cost estimates presented here represent an expected incremental cost of the engine or piece of equipment in the model year of introduction. Variable costs in subsequent years would be reduced by several factors, as described below. All costs are presented in 2001 dollars.

6.2 Engine-Related Costs

6.2.1 Engine Fixed Costs

6.2.1.1 Engine and Emission Control Device R&D

The technologies described in Chapter 4 of this Draft RIA represent those technologies we believe will be used to comply with the proposed Tier 4 emission standards. These technologies are also part of an ongoing research and development effort geared toward compliance with the 2007 heavy-duty diesel highway emission standards. Those engine manufacturers making R&D expenditures toward compliance with highway emission standards will have to undergo some R&D effort to transfer emission control technologies to engines they wish to sell into the nonroad market. These R&D efforts will allow engine manufacturers to develop and optimize these new technologies for maximum emission-control effectiveness with minimum negative impacts on engine performance, durability, and fuel consumption. However, many nonroad engine manufacturers are not part of the ongoing R&D effort toward compliance with highway emissions standards because they do not sell engines into the highway market. These manufacturers are expected to learn from the R&D work that has already occurred and will continue through the coming years through their contact with highway manufacturers, emission control device manufacturers, and the independent engine research laboratories conducting relevant R&D. Despite these opportunities for learning, we would expect the R&D expenditures for these nonroad-only manufacturers to be somewhat higher than for those manufacturers already conducting R&D in response to the HD2007 rule.

We are projecting that several technologies will be used to comply with the proposed Tier 4 emission standards. We are projecting that NOx adsorbers and CDPFs would be the most likely technologies applied by industry to meet our proposed emissions standards for >75 horsepower engines and, for engines between 25 and 75 horsepower, that CDPFs would be used in 2013 to meet the proposed PM standard. The fact that these technologies are being developed for implementation in the highway market prior to the implementation dates in today’s proposal, and the fact that engine manufacturers would have several years before implementation of the proposed Tier 4 standards, ensures that the technologies used to comply with the nonroad standards would undergo significant development before reaching production. This ongoing development could lead to reduced costs in three ways. First, we expect research will lead to enhanced effectiveness for individual technologies, allowing manufacturers to use simpler packages of emission control technologies than we would predict given the current state of development. Similarly, we anticipate that the continuing effort to improve the emission control technologies will include innovations that allow lower-cost production. Finally, we believe that manufacturers would focus research efforts on any drawbacks, such as fuel economy impacts or maintenance costs, in an effort to minimize or overcome any potential negative effects.

We anticipate that, in order to meet the proposed standards, industry would introduce a combination of primary technology upgrades. Achieving very low NOx emissions would require basic research on NOx emission control technologies and improvements in engine management to take advantage of the exhaust emission control system capabilities. The manufacturers are expected to take a systems approach to the problem of optimizing the engine and exhaust emission control system to realize the best overall performance. Since most research to date with exhaust emission control technologies has focused on retrofit programs, there remains room for significant improvements by taking such a systems approach. The NOx adsorber technology in particular is expected to benefit from re-optimization of the engine management system to better match the NOx adsorber’s performance characteristics. The majority of the dollars we have estimated for research is expected to be spent on developing this synergy between the engine and NOx exhaust emission control systems. Therefore, for engines requiring both a CDPF and a NOx adsorber (i.e., >75 horsepower), we have attributed two-thirds of the R&D expenditures to NOx control, and one-third to PM control.

In the 2007 highway rule, we estimated that each engine manufacturer would expend $35 million for R&D toward a successful implementation of catalyzed diesel particulate filters

(CDPF) and NOx adsorbers. For their nonroad R&D efforts on engines requiring CDPFs and NOx adsorbers (i.e., >75 horsepower), engine manufacturers selling into the highway market would incur some level of R&D effort but not at the level incurred for the highway rule. In many cases, the engines used by highway manufacturers in nonroad products are based on the same engine platform as those engines used in highway products. However, horsepower and torque characteristics are often different so some effort will have to be expended to accommodate those differences. Therefore, for these manufacturers, we have estimated that they would incur an R&D expense 10 percent of that incurred for the highway rule, or $3.5 million. This $3.5 million R&D expense would allow for the transfer of R&D knowledge from their highway experience to their nonroad engine product line. For reasons noted above, two-thirds of this R&D is attributed to NOx control and one-third to PM control.

For those manufacturers that sell engines only into the nonroad market, and where those engines require a CDPF and a NOx adsorber, we believe that they will incur an R&D expense nearing but not equaling that incurred by highway manufacturers for the highway rule. Nonroad manufacturers would be able to learn from the R&D efforts already underway for both the highway rule and for the Tier 2 light-duty highway rule (65 FR 6698). This learning could be done via seminars, conferences, and contact with highway manufacturers, emission control device manufacturers, and the independent engine research laboratories conducting relevant R&D. Therefore, we have estimated an expenditure of 70 percent of that spent by highway manufacturers in their highway efforts. This lower number—$24.5 million versus $35 million in the highway rule—reflects the transfer of knowledge to nonroad manufacturers from the many other stakeholders in the diesel industry. As noted above, two-thirds of this R&D is attributed to NOx control and one-third to PM control.

Note that the $3.5 million and $24.5 million estimates represent our estimate of the average R&D expected by manufacturers. These estimates would be different for each manufacturer – some higher, some lower – depending on product mix and the ability to transfer knowledge from one product to another.

For those engine manufacturers selling engines that would require CDPF-only R&D (i.e., 25 to 75 horsepower engines in 2013), we have estimated that the R&D they would incur would be roughly one-third that incurred by manufacturers conducting CDPF/NOx adsorber R&D. We believe this is a reasonable estimate because CDPF technology is further along in its development than is NOx adsorber technology and, therefore, a 50/50 split would not be appropriate. Using this estimate, the R&D incurred by manufacturers selling any engines into both the highway and the nonroad markets would be $1.2 million, and the R&D for manufacturers selling engines into only the nonroad market would be roughly $8 million. All of this R&D is attributed to PM control.

For those engine manufacturers selling engines that would require DOC-only or some engine-out modification R&D (i.e., to meet the PM standard on <75 horsepower engines in 2008), we have estimated that the R&D they would incur would be roughly one-half the amount estimated for their CDPF-only R&D. Application of a DOC should require very little R&D effort because these devices have been around for years and because they require no special fueling strategies or operating conditions to operate properly. Nonetheless, to be conservative we have estimated that the R&D incurred by manufacturers selling any engines into both the highway and nonroad markets would be roughly $600,000, and the R&D for manufacturers selling engines into only the nonroad market would be roughly $4 million. Because these R&D expenditures are strictly for meeting a PM standard, all of this R&D is attributed to PM control.

All of these R&D estimates are outlined in Table 6.2-1.

Table 6.2-1
Estimated R&D Expenditures by Type of Manufacturer
Totals per Manufacturer over Five Years

	R&D for CDPF&NOx Adsorber Engines	R&D for CDPF-only Engines	R&D for DOC/engine-out Engines
For proposed standards starting in year	2011 & 2012	2013	2008
Horsepower Range	hp≥75	25≤hp<75	0<hp<75
Manufacturer sells into both highway and nonroad markets	$3,500,000		$577,500
Manufacturer sells into only the nonroad market	$24,500,000		$4,042,500
Manufacturer has already done CDPF&NOx Adsorber R&D		$1,155,000	
Manufacturer has not done CDPF&NOx Adsorber R&D		$8,085,000	
% Allocated to PM	33%	100%	100%
% Allocated to NOx	67%		

To determine which manufacturers would incur which levels of R&D, we used certification data for the 2002 model year. Throughout this analysis, we have assumed that the manufacturers that certified engines for 2002 are the manufacturers under consideration for the proposed standards. When certifying engines, manufacturers project the sales of each engine they certify. This projected sales information is confidential business information and cannot be shared and, therefore, we cannot share our estimated R&D expenditures on a manufacturer by manufacturer basis.

Using the projected sales information, we were able to determine how many engine sales each manufacturer expects to have in each of the horsepower categories of interest. As a result, not every manufacturer is expected to incur all of the R&D costs shown in Table 6.2-1. For example, some manufacturers do not certify engines below 75 horsepower. Such a manufacturer would not incur R&D costs for CDPF-only engines or for those engines expected to add a DOC or make only engine-out changes. Also, some engine manufacturers produce and sell engines to specifications developed by other manufacturers. Such joint venture manufacturers or wholly owned manufacturers do not conduct engine-related R&D but simply manufacture an engine designed and developed by another manufacturer. For such manufacturers, we have assumed no engine R&D expenditures given that we believe they would conduct no R&D themselves and would rely on their joint venture partner. This is true unless the parent company has no engine sales in the horsepower categories covered by the partner company. Under such a situation, we have accounted for the necessary R&D by attributing it to the parent company. For example, Perkins is an engine manufacturer wholly owned by Caterpillar so we have attributed no R&D costs to Perkins. However, Perkins sells engines in horsepower categories that Caterpillar does not. As a result, we have attributed R&D costs to Caterpillar for conducting R&D that would benefit Perkins engines. We have identified nine manufacturers to whom we have attributed no R&D because of a joint partner agreement.[B] Some of these (e.g., Perkins) we have attributed R&D costs to their parent for the engines they will sell, and some are essentially the same company as their parent (e.g., Detroit Diesel and their parent DaimlerChrysler, New Holland and their parent CNH). In the end, it is not important to our analysis to what manufacturer the R&D is allocated because we have attempted to estimate the total R&D that would be spent by the entire industry.

We have also estimated that some manufacturers will choose not to invest in R&D for the U.S. nonroad market due to low volume sales that cannot justify the expense. We have identified three such manufacturers to whom we have attributed no R&D due to the cost of that R&D relative to our best estimate of their revenues.[C] This is not to say that we believe these manufacturers will cease to do business or even choose to leave the market; it only means that, given their low U.S. sales volumes, we believe it is unlikely that they would conduct the necessary R&D themselves. Instead, they would probably license the technology from another manufacturer which would serve to increase their own costs but reduce the net costs incurred by the licensing manufacturer; all while having no impact on the total costs of the rule. Because the determination of which manufacturers would and would not invest in R&D is based on projected sales data, we cannot share the manufacturer names. It is important to note that the total projected sales for all three engine manufacturers was 77 engines in the 2002 model year.

[B] Detroit Diesel and VM Motori were treated as part of DaimlerChrysler; IVECO, New Holland, and CNH were treated as one; Kirloskar and Kukje were treated as a partner of Cummins; Mitsubishi Motors Corporation and Mitsubishi Heavy Industries are treated as one company; Perkins R&D is attributed to Caterpillar; and, Volvo Construction Equipment and Volvo Penta AB are treated as one company.

[C] Estimated engine prices are shown in Table 6.2-3. We multiplied these prices by the manufacturer’s projected sales volume to determine if projected revenues from engine sales would exceed our estimated R&D costs. If not, we have assumed that the manufacturer would not invest in the R&D and would, instead, license the R&D from another manufacturer. While this would result in costs to the licensing manufacturer, it would also result in profits to the licensor; therefore, it would not result in increased costs associated with the proposed standards.

Lastly, some certifying manufacturers do not appear to actually make engines. Instead, they purchase engines from another engine manufacturer and then certify it as their own. We have identified eight such certifying manufacturers and have attributed no R&D to these eight.[D]

Excluding the manufacturers we have identified as being in a joint partner arrangement or as unlikely to invest in R&D, there remain 20 manufacturers expected to invest in CDPF&NOx Adsorber R&D, 27 manufacturers expected to invest in CDPF-only R&D, and 28 manufacturers expected to invest in DOC/engine-out R&D. The total estimated R&D expenditures are shown in Table 6.2-2.

Table 6.2-2
Estimated Industrywide R&D Expenditures for the Proposed Nonroad Tier 4 Standards[a]

	DOC/engine-out R&D[b]	CDPF+NOx Adsorber R&D[b]	CDPF-only R&D[b]	Total R&D[b]
Expenditures during Years:	2003-2007	2006-2011	2008-2012	2003-2012
Horsepower	0<hp<75	≥75hp	25≤hp<75	all hp
Total Industry-wide R&D Expenditures	$36.0	$118.0	$45.2	$199.2
R&D for PM	$36.0	$38.9	$45.2	$120.1
R&D for NOx	—	$79.0	—	$79.0

[a] Dollar Values are in millions of 2001 dollars.
[b] Total R&D attributable to proposed U.S. standards (see discussion in text).

We have estimated that all engine-related R&D expenditures occur over a five year span preceding the first year any emission control device is introduced into the market. Those expenditures are then recovered by the engine manufacturer during any phase-in years and then over a five year span following introduction of the technology. As a result of the lack of PM phase-ins, most PM costs are recovered for five years following the first year of implementation. Most NOx costs are recovered over the two or three year phase-in and then five years following complete implementation, or a total of seven or eight years. We assume a seven percent rate of return for all R&D.

Our R&D estimates represent the cost to develop advanced aftertreatment based emission control systems enabled by <15 ppm sulfur diesel fuel. We are projecting that manufacturers would need to do this R&D to sell engines in Europe, Japan, Australia, and Canada because we expect that similar emission standards would be required on a similar timeframe for each of these regions or countries.[7] Therefore, we have attempted to attribute the costs of R&D to the total

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[D] These eight are: Alaska Diesel Electric; American Jawa; Eastern Tools and Equipment; Escorts, Ltd.; Harvest Drivemaster USA; International Tractors; Northern Tool and Equipment; Same Deutz-Fahr Group.

engine sales for these regions. Since we do not have sales data for every manufacturer showing what percent of their engines are sold in the US relative to these other regions, we have used Gross Domestic Product (GDP) as a surrogate for sales. As a result, we have attributed only a portion of the R&D expenditures to engine sales within the United States. Of the countries expected to have nonroad emission standards of similar stringency to our proposed standards, U.S. GDP constitutes 42 percent of the total.[E] Therefore, we have attributed 42 percent of the R&D costs to U.S. sales.

We have weighted R&D recovery according to estimated revenues for engines sold in each horsepower category. For example, CDPF&NOx Adsorber R&D benefits all engines above 75 horsepower. However, engines above 175 horsepower must introduce the new technologies in 2011, while engines from 75 to 175 horsepower would introduce it a year later. As a result, R&D costs are assumed to be recovered on >175 horsepower engines between 2011 and 2015/2018 and on 75 to 175 horsepower engines between 2012 and 2016/2018. Delaying implementation dates for these engines, or a subset of these engines, would not impact our estimated R&D expenditures or their recovery but would, instead, only affect the timing of their recovery. To weight the costs between engines in these categories, we have used revenue weighting rather than a more simplistic sales weighting under the belief that manufacturers would attempt to recover more costs where more revenues occur. Revenue weighting is simply an estimated price multiplied by a unit sales figure. The revenue weightings we have used are shown in Table 6.2-3.

Using this methodology, we have estimated the total R&D expenditures attributable to the proposed standards at $7 to $33 million per year depending on the year, with an average of $18 million per year and a total of $199 million. Total R&D recovery on U.S. sales is estimated at $279 million. All estimated R&D costs are shown in Table 6.2-4. Note that the engine sales numbers shown in Table 6.2-4 are discussed in greater detail in Chapter 8 of this Draft RIA where we present aggregate costs to society.

[E] According to the Worldbank, in 2000, the European countries of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, and the United Kingdom had a combined GDP of $7.8B; Australia's GDP was $0.4B; Canada's GDP was $0.7B; Japan's GDP was $4.7B; and the U.S. GDP was $9.9B; for a total GDP of $23.5B (www.worldbank.org).

Table 6.2-3
Revenue Weightings Used to Allocate R&D Cost Recovery

Horsepower	2000 Sales	Estimated Engine Price	Revenue Weighted Recovery of R&D in the Indicated Years				
			PM	2008-2012	2011-2015	2012-2016	2013-2017
			NOx	N/A	2011-2018	2012-2018	N/A
0<hp<25	119,159	$1,500		22%			
25≤hp<50	132,981	$2,800		46%			59%
50≤hp<75	93,914	$2,800		32%			41%
75≤hp<100	68,665	$5,000				11%	
100≤hp<175	112,340	$5,000				17%	
175≤hp<300	61,851	$10,000			26%	19%	
300≤hp<600	34,095	$30,000			44%	32%	
600≤hp≤750	2,752	$125,000			15%	10%	
hp>750	2,785	$125,000			15%	11%	
Total	628,542			100%	100%	100%	100%

Table 6.2-4

Estimated R&D Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2001

Thousands of dollars, except per engine values

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
0<hp<25	Estimated US Sales	131,507	135,623	139,739	143,855	147,971	152,087	156,203	160,319	164,435	168,551	172,667	176,783	180,899	185,015	189,131	193,247	193,247	193,247	
	PM Costs Incurred	$1,581	$1,581	$1,581	$1,581	$1,581														$7,905
	NOx Costs Incurred																			$0
	PM Costs Recovered						$2,218	$2,218	$2,218	$2,218	$2,218									$11,088
	NOx Costs Recovered																			$0
	Per Engine Cost						$15	$14	$14	$13	$13									
25<=hp<50	Estimated US Sales	143,496	147,001	150,506	154,011	157,516	161,021	164,526	168,031	171,536	175,041	178,546	182,051	185,556	189,061	192,566	196,071	196,071	196,071	
	PM Costs Incurred	$3,294	$3,294	$3,294	$3,294	$3,294	$5,304	$5,304	$5,304	$5,304	$5,304									$42,988
	NOx Costs Incurred																			$0
	PM Costs Recovered						$4,620	$4,620	$4,620	$4,620	$4,620	$7,439	$7,439	$7,439	$7,439	$7,439				$60,294
	NOx Costs Recovered																			$0
	Per Engine Cost						$29	$28	$27	$27	$26	$42	$41	$40	$39	$39				
50<=hp<75	Estimated US Sales	100,051	102,097	104,142	106,188	108,234	110,279	112,325	114,371	116,416	118,462	120,507	122,553	124,599	126,644	128,690	130,736	130,736	130,736	
	PM Costs Incurred	$2,326	$2,326	$2,326	$2,326	$2,326	$3,746	$3,746	$3,746	$3,746	$3,746									$30,359
	NOx Costs Incurred																			$0
	PM Costs Recovered						$3,262	$3,262	$3,262	$3,262	$3,262	$5,254	$5,254	$5,254	$5,254	$5,254				$42,581
	NOx Costs Recovered																			$0
	Per Engine Cost						$30	$29	$29	$28	$28	$44	$43	$42	$41	$41				
75<=hp<100	Estimated US Sales	73,162	74,662	76,161	77,660	79,159	80,659	82,158	83,657	85,157	86,656	88,155	89,654	91,154	92,653	94,152	95,652	95,652	95,652	
	PM Costs Incurred					$825	$825	$825	$825	$628										$3,929
	NOx Costs Incurred					$838	$838	$1,676	$1,676	$1,016	$838	$838								$7,718
	PM Costs Recovered										$1,158	$1,158	$1,158	$1,158	$880					$5,510
	NOx Costs Recovered										$1,175	$1,175	$2,350	$2,350	$1,425	$1,175	$1,175			$10,825
	Per Engine Cost										$27	$26	$39	$38	$25	$12	$12			
100<=hp<175	Estimated US Sales	119,303	121,625	123,946	126,267	128,588	130,909	133,230	135,551	137,872	140,193	142,514	144,836	147,157	149,478	151,799	154,120	154,120	154,120	
	PM Costs Incurred					$1,350	$1,350	$1,350	$1,350	$1,027										$6,428
	NOx Costs Incurred					$1,371	$1,371	$2,741	$2,741	$1,662	$1,371	$1,371								$12,627
	PM Costs Recovered										$1,894	$1,894	$1,894	$1,894	$1,440					$9,015
	NOx Costs Recovered										$1,922	$1,922	$3,845	$3,845	$2,331	$1,922	$1,922			$17,711
	Per Engine Cost										$27	$27	$40	$39	$25	$13	$12			
175<=hp<300	Estimated US Sales	66,093	67,507	68,921	70,335	71,749	73,163	74,577	75,991	77,405	78,819	80,233	81,647	83,061	84,475	85,889	87,303	87,303	87,303	
	PM Costs Incurred				$1,625	$1,487	$1,487	$1,487	$1,487											$7,572
	NOx Costs Incurred				$1,650	$1,509	$1,509	$3,019	$3,019	$1,830	$1,509	$1,509								$15,554
	PM Costs Recovered									$2,279	$2,085	$2,085	$2,085	$2,085						$10,620
	NOx Costs Recovered									$2,314	$2,117	$2,117	$4,234	$4,234	$2,567	$2,117	$2,117			$21,815
	Per Engine Cost									$59	$53	$52	$77	$76	$30	$25	$24			
300<=hp<600	Estimated US Sales	35,403	35,839	36,275	36,711	37,147	37,583	38,019	38,455	38,891	39,327	39,763	40,199	40,635	41,071	41,507	41,943	41,943	41,943	
	PM Costs Incurred				$2,687	$2,459	$2,459	$2,459	$2,459											$12,522
	NOx Costs Incurred				$2,728	$2,496	$2,496	$4,992	$4,992	$3,026	$2,496	$2,496								$25,722
	PM Costs Recovered									$3,769	$3,449	$3,449	$3,449	$3,449						$17,563
	NOx Costs Recovered									$3,826	$3,501	$3,501	$7,002	$7,002	$4,245	$3,501	$3,501			$36,077
	Per Engine Cost									$195	$177	$175	$260	$257	$103	$84	$83			
600<=hp<=750	Estimated US Sales	2,902	2,952	3,002	3,052	3,102	3,152	3,202	3,252	3,302	3,352	3,402	3,452	3,502	3,552	3,602	3,652	3,652	3,652	
	PM Costs Incurred				$904	$827	$827	$827	$827											$4,211
	NOx Costs Incurred				$917	$839	$839	$1,679	$1,679	$1,018	$839	$839								$8,651
	PM Costs Recovered									$1,268	$1,160	$1,160	$1,160	$1,160						$5,907
	NOx Costs Recovered									$1,287	$1,177	$1,177	$2,355	$2,355	$1,428	$1,177	$1,177			$12,133
	Per Engine Cost									$774	$697	$687	$1,018	$1,004	$402	$327	$322			
>750hp	Estimated US Sales	2,938	2,989	3,040	3,091	3,142	3,193	3,244	3,295	3,346	3,397	3,448	3,499	3,550	3,601	3,652	3,703	3,703	3,703	
	PM Costs Incurred				$915	$837	$837	$837	$837											$4,262
	NOx Costs Incurred				$928	$850	$850	$1,699	$1,699	$1,030	$850	$850								$8,755
	PM Costs Recovered									$1,283	$1,174	$1,174	$1,174	$1,174						$5,978
	NOx Costs Recovered									$1,302	$1,191	$1,191	$2,383	$2,383	$1,445	$1,191	$1,191			$12,279
	Per Engine Cost									$773	$696	$686	$1,016	$1,002	$401	$326	$322			
All hp	PM Costs Incurred	$7,201	$7,201	$7,201	$13,331	$14,986	$16,835	$16,835	$16,835	$10,704	$9,050									$120,177
	NOx Costs Incurred				$6,223	$7,903	$7,903	$15,805	$15,805	$9,582	$7,903	$7,903								$79,027
	Total Costs Incurred	$7,201	$7,201	$7,201	$19,555	$22,888	$24,737	$32,640	$32,640	$20,286	$16,952	$7,903								$199,204
	PM Costs Recovered						$10,100	$10,100	$10,100	$18,698	$21,018	$23,611	$23,611	$23,611	$15,013	$12,693				$168,555
	NOx Costs Recovered									$8,729	$11,084	$11,084	$22,168	$22,168	$13,439	$11,084	$11,084			$110,839
	Total Costs Recovered						$10,100	$10,100	$10,100	$27,427	$32,102	$34,695	$45,779	$45,779	$28,452	$23,777	$11,084			$279,394

6.2.1.2 Engine-Related Tooling Costs

Once engines are ready for production, new tooling will be required to accommodate the assembly of the new engines. In the 2007 highway rule, we estimated approximately $1.6 million per engine line for tooling costs associated with CDPF/NOx adsorber systems. For the proposed nonroad Tier 4 standards, we have estimated that nonroad-only manufacturers would incur the same $1.6 million per engine line requiring a CDPF/NOx adsorber system and that these costs would be split evenly between NOx control and PM control. We have estimated the same tooling costs as estimated in the 2007 highway rule because we expect these Tier 4 engines would use the same technologies as the 2007 highway rule (i.e., a CDPF and a NOx adsorber). For those systems requiring only a CDPF, we have estimated one-half that amount, or $800,000 per engine line. For those systems requiring only a DOC or some engine-out modifications, we have estimated one-half the CDPF-only amount, or $400,000 per engine line. Tooling costs for CDPF-only and for DOC engines are attributed solely to PM control.

For those manufacturers selling into both the highway and nonroad markets, we have started with the same $1.6 million baseline discussed above. For those engines requiring a CPDF/NOx adsorber system (i.e., those >75 horsepower) we have adjusted that $1.6 million baseline by 50 percent. We believe this 50 percent adjustment is reasonable since many nonroad engines over 75 horsepower are produced on the same engine line with their highway counterparts. For such lines, essentially no tooling costs would be incurred. For engine lines without a highway counterpart, the $1.6 million tooling cost would be applicable. For highway manufacturers selling into both the highway and the nonroad markets, we have assumed a 50/50 split of nonroad engine product lines (i.e., 50 percent with highway counterparts and 50 percent without) and, therefore, a 50 percent factor applied to the $1.6 million baseline. These tooling costs would be split evenly between NOx control and PM control. For those engine lines requiring only a CDPF (i.e., those between 25 and 75 horsepower), we have estimated the same tooling cost as used for nonroad-only manufacturers, or $800,000. Similarly, the tooling costs for DOC and/or engine-out engine lines has been estimated to be $400,000. We have used the same tooling costs as the nonroad-only manufacturers for the <75 horsepower engines because these engines tend not to have a highway counterpart. Tooling costs for CDPF-only and for DOC engines are attributed solely to PM control.

We have projected that engines in the 25 to 50 horsepower range would apply EGR systems to meet the proposed NOx standards for 2013. For these engines, we have included an additional tooling cost of $40,000 per engine line, consistent with the EGR-related tooling cost estimated for 50-100 horsepower engines in our Tier 2/3 rulemaking where the same NOx standards was required. This tooling cost is applied equally to all engine lines in that horsepower range regardless of the markets into which the manufacturer sells. We have applied this tooling cost equally because engines in this horsepower range do not tend to have highway counterparts. Because EGR systems are expected to be added to engines between 25 and 50 horsepower to meet the proposed NOx standard, tooling costs for EGR systems are attributed solely to NOx control.

Tooling costs per engine line and type of manufacturer are summarized in Table 6.2-5.

Table 6.2-5
Estimated Tooling Expenditures per Engine Line by Type of Manufacturer

	DOC/engine-out Engines	CDPF-only Engines	CDPF & NOx Adsorber Engines	EGR Engines
Horsepower Range	0<hp<75	25≤hp<75	hp≥75	25≤hp<50
For proposed standards starting in	2008	2013	2011/2012	2013
Manufacturer sells into both highway & nonroad markets	$400,000	$800,000	$800,000	$40,000
Manufacturer sells into only the nonroad market	$400,000	$800,000	$1,600,000	$40,000
% Allocated to PM	100%	100%	50%	0%
% Allocated to NOx	0%	0%	50%	100%

As noted, we have applied tooling costs by engine line assuming that engines in the same line are produced on the same production line. Typically, the same basic diesel engine design can be increased or decreased in size by simply adding or subtracting cylinders. As a result, a four, six, eight, etc., cylinder engine may be produced from the same basic engine design. While these engines would have different displacements, the added or subtracted cylinders would have the same displacement per cylinder. Using the PSR database, we grouped each engine manufacturer’s engines into distinct engine lines using increments of 0.5 liters per cylinder. This way, engines having similar displacements per cylinder are grouped together and are considered to be built on the same production line. Note that a tooling expenditure for a single engine line may cover engines over several horsepower categories. To allocate the tooling expenditure for a given production line to a specific horsepower range, we have used sales weighting within that engine line.

We have applied all the above tooling costs to all manufacturers that appear to actually make engines. We have not eliminated joint venture manufacturers because these manufacturers would still need to invest in tooling to make the engines even if they do not conduct any R&D. Doing this, we determined there to be 62 manufacturers expected to invest in tooling for a total of 133 engine lines. Of these, 19 manufacturers sell into both the highway and nonroad markets and sell a total of 56 engine lines, while 43 manufacturers sell into only the nonroad market and sell a total of 77 engine lines. For the same reasons as explained for R&D costs, we have attributed a portion of the tooling costs to U.S. sales and a portion to sales in other countries expected to have similar levels of emission control. All tooling costs are assumed to be incurred one year prior to the standard they support and are then recovered over a five year period following introduction of the new standard. For engines >750 hp, half of the tooling costs are incurred one year ahead of 2011 and the other half are incurred one year ahead of 2014 due to the 50/50/50/100 percent phase-in that begins in 2011. The costs are then recovered over an eight year period due to this phase-in. A seven percent interest rate is used to account for the time value of money.

Using this methodology, we estimate the total tooling expenditures attributable to the proposed standards at $67 million. Total tooling recovery on U.S. sales is estimated at $81 million. All estimated tooling costs are shown in Table 6.2-6.

Table 6.2-6

Estimated Tooling Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2001

Thousands of dollars, except per engine values

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
0<hp<25	Estimated US Sales	147,971	152,087	156,203	160,319	164,435	168,551	172,667	176,783	180,899	185,015	189,131	193,247	193,247	
	PM Costs Incurred	$3,365													$3,365
	NOx Costs Incurred														$0
	PM Costs Recovered		$821	$821	$821	$821	$821								$4,104
	NOx Costs Recovered														$0
	Per Engine Cost		$5	$5	$5	$5	$5								
25<=hp<50	Estimated US Sales	157,516	161,021	164,526	168,031	171,536	175,041	178,546	182,051	185,556	189,061	192,566	196,071	196,071	
	PM Costs Incurred	$3,756					$4,148								$7,903
	NOx Costs Incurred						$506								$506
	PM Costs Recovered		$916	$916	$916	$916	$916	$1,012	$1,012	$1,012	$1,012	$1,012			$9,638
	NOx Costs Recovered							$123	$123	$123	$123	$123			$616
	Per Engine Cost		$6	$6	$5	$5	$5	$6	$6	$6	$6	$6			
50<=hp<75	Estimated US Sales	108,234	110,279	112,325	114,371	116,416	118,462	120,507	122,553	124,599	126,644	128,690	130,736	130,736	
	PM Costs Incurred	$2,652					$2,929								$5,582
	NOx Costs Incurred														$0
	PM Costs Recovered		$647	$647	$647	$647	$647	$714	$714	$714	$714	$714			$6,806
	NOx Costs Recovered														$0
	Per Engine Cost		$6	$6	$6	$6	$5	$6	$6	$6	$6	$6			
75<=hp<100	Estimated US Sales	79,159	80,659	82,158	83,657	85,157	86,656	88,155	89,654	91,154	92,653	94,152	95,652	95,652	
	PM Costs Incurred					$2,685									$2,685
	NOx Costs Incurred					$2,685									$2,685
	PM Costs Recovered						$655	$655	$655	$655	$655				$3,274
	NOx Costs Recovered						$655	$655	$655	$655	$655				$3,274
	Per Engine Cost						$15	$15	$15	$14	$14				
100<=hp<175	Estimated US Sales	128,588	130,909	133,230	135,551	137,872	140,193	142,514	144,836	147,157	149,478	151,799	154,120	154,120	
	PM Costs Incurred					$4,392									$4,392
	NOx Costs Incurred					$4,392									$4,392
	PM Costs Recovered						$1,071	$1,071	$1,071	$1,071	$1,071				$5,356
	NOx Costs Recovered						$1,071	$1,071	$1,071	$1,071	$1,071				$5,356
	Per Engine Cost						$15	$15	$15	$15	$14				
175<=hp<300	Estimated US Sales	71,749	73,163	74,577	75,991	77,405	78,819	80,233	81,647	83,061	84,475	85,889	87,303	87,303	
	PM Costs Incurred				$10,665										$10,665
	NOx Costs Incurred				$10,665										$10,665
	PM Costs Recovered					$2,601	$2,601	$2,601	$2,601	$2,601					$13,006
	NOx Costs Recovered					$2,601	$2,601	$2,601	$2,601	$2,601					$13,006
	Per Engine Cost					$67	$66	$65	$64	$63					
300<=hp<600	Estimated US Sales	37,147	37,583	38,019	38,455	38,891	39,327	39,763	40,199	40,635	41,071	41,507	41,943	41,943	
	PM Costs Incurred				$5,879										$5,879
	NOx Costs Incurred				$5,879										$5,879
	PM Costs Recovered					$1,434	$1,434	$1,434	$1,434	$1,434					$7,169
	NOx Costs Recovered					$1,434	$1,434	$1,434	$1,434	$1,434					$7,169
	Per Engine Cost					$74	$73	$72	$71	$71					
600<=hp<=750	Estimated US Sales	3,102	3,152	3,202	3,252	3,302	3,352	3,402	3,452	3,502	3,552	3,602	3,652	3,652	
	PM Costs Incurred				$475										$475
	NOx Costs Incurred				$475										$475
	PM Costs Recovered					$116	$116	$116	$116	$116					$579
	NOx Costs Recovered					$116	$116	$116	$116	$116					$579
	Per Engine Cost					$70	$69	$68	$67	$66					
>750hp	Estimated US Sales	3,142	3,193	3,244	3,295	3,346	3,397	3,448	3,499	3,550	3,601	3,652	3,703	3,703	
	PM Costs Incurred				$253			$253							$506
	NOx Costs Incurred				$253			$253							$506
	PM Costs Recovered					$62	$62	$62	$123	$123	$62	$62	$62		$616
	NOx Costs Recovered					$62	$62	$62	$123	$123	$62	$62	$62		$616
	Per Engine Cost					$37	$36	$36	$70	$69	$34	$34	$33		
All hp	PM Costs Incurred	$9,773			$17,271	$7,077	$7,077	$253							$41,451
	NOx Costs Incurred				$17,271	$7,077	$506	$253							$25,107
	Total Costs Incurred	$9,773			$34,543	$14,154	$7,583	$506							$66,558
	PM Costs Recovered		$2,384	$2,384	$2,384	$6,596	$8,322	$7,664	$7,726	$7,726	$3,514	$1,788	$62		$50,548
	NOx Costs Recovered					$4,212	$5,938	$6,062	$6,123	$6,123	$1,911	$185	$62		$30,616
	Total Costs Recovered		$2,384	$2,384	$2,384	$10,808	$14,260	$13,726	$13,849	$13,849	$5,425	$1,973	$123		$81,164

6.2.1.3 Engine Certification Costs

Manufacturers will incur more than the normal level of certification costs during the first few years of implementation because engines will need to be certified to the new emission standards. Consistent with our recent standard setting regulations, we have estimated engine certification costs at $60,000 per new engine certification to cover testing and administrative costs.[8] To this we have added the proposed certification fee of $2,156 per new engine family.[9] This cost, $62,156 per engine family was used for <75 horsepower engines certifying to the 2008 standards. For 25 to 75 horsepower engines certifying to the 2013 standards, and for >75 horsepower engines certifying to their proposed standards, we have added costs to cover the proposed test procedures for nonroad diesel engines (i.e., the transient test and the NTE); these costs were estimated at $10,500 per engine family. These certification costs—whether it be the $62,156 or the $72,656 per engine family—apply equally to all engine families for all manufacturers regardless of the markets into which the manufacturer sells.

To determine the number of engine families to be certified, we used our certification database for the 2002 model year. That database provides the number of engine families and the associated horsepower rating of each. We grouped those horsepower ratings into the nine horsepower ranges shown in Table 6.2-7. We have chosen these nine horsepower categories for a couple of reasons: (1) phase-ins of standards and/or different levels of baseline versus proposed standards force such breakouts; and, (2) greater stratification (i.e., breaking up the 75 to 175 horsepower range and the 175 to 750 horsepower range) provides a better picture of cost recovery because it more accurately matches the number of engine families (certification costs) with the level of engine sales (cost recovery). Some engine families will undergo more than one certification process due to the structure of the proposed engine standards. Table 6.2-7 shows the number of engine families in each horsepower range and the year for which they would have to be certified to new standards, along with the total certification expenditures for those standards.

The cost expenditures shown in Table 6.2-7 would be incurred one year prior to the years shown in the table. The years shown in the table coincide with the years for which the new standards begin thereby forcing the certification of engines. Half of the 175 to 750 horsepower engine families certified for 2011 must again be certified in 2014 when the NOx phase-in becomes 100 percent. Half of the >750 horsepower engine families get certified in 2011 and the remaining half get certified in 2014 due to the 50/50/50/100 percent PM & NOx phase-ins. For the 25 to 50 horsepower engine families in 2013, half of the certification costs are attributed to PM while half are attributed to NOx due to the proposal to add new PM and NOx standards for those engines in that year; all of the certification costs for 50 to 75 horsepower engine families are attributed to PM because only a new PM standard would be implemented in that year for those engines.

Note that these certification costs should be considered conservative because they assume all engines are certified because of the proposed standards. In reality, some engines would have been certified due to factors independent of the proposed standards. Such engines would have incurred certification costs regardless of any new standards.

Table 6.2-7
Number of Engine Families, Estimated Certification Costs in $2001,
and Allocation of Certification Costs

Horsepower Range	For Proposed Emissions Standards Starting in the Year							
	2008	2011	2012	2013		2014		
0<hp<25	102							
25≤hp<50	132			132				
50≤hp<75	88				88			
75≤hp<100			55					28
100≤hp<175			73					37
175≤hp<300		102				51		
300≤hp<600		64				32		
600≤hp≤750		9				5		
hp>750[a]		20					20	
Total families	322	195	128	132	88	88	20	64
Total Cert Costs ($MM)	$20.0	$14.2	$9.3	$9.6	$6.4	$6.4	$1.5	$4.7
% Allocated to PM	100%	50%	50%	50%	100%	0%	50%	0%
% Allocated to NOx	0%	50%	50%	50%	0%	100%	50%	100%

[a] Forty engine families were certified in the >750 hp range, but only half would be certified in the indicated years due to the proposed phase-in schedule.

To estimate recovery of certification expenditures, we have attributed the expenditures to engines sold in the specific horsepower range and spread the recovery of costs over U.S. sales within that category. Expenditures are incurred one year prior to the emission standard for which the certification is conducted, and are then recovered over a five year period following the certification. A seven percent interest rate is used to account for the time value of money. We have spread these certification costs over only the U.S.-sold engines because the certification conducted for the U.S. is not presumed to fulfill the certification requirements of other countries. Total certification expenditures were estimated at $72 million. Recovery of certification costs was estimated at $88 million. All estimated certification expenditures and the recovery of those expenditures are shown in Table 6.2-8.

Table 6.2-8

Estimated Certification Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2001

Thousands of dollars, except per engine values

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
0<hp<25	Estimated US Sales	147,971	152,087	156,203	160,319	164,435	168,551	172,667	176,783	180,899	185,015	189,131	193,247	193,247	
	PM Costs Incurred	$6,340													$6,340
	NOx Costs Incurred														$0
	PM Costs Recovered		$1,546	$1,546	$1,546	$1,546	$1,546								$7,731
	NOx Costs Recovered														$0
	Per Engine Cost		$10	$10	$10	$9	$9								
25<=hp<50	Estimated US Sales	157,516	161,021	164,526	168,031	171,536	175,041	178,546	182,051	185,556	189,061	192,566	196,071	196,071	
	PM Costs Incurred	$8,205					$4,795								$13,000
	NOx Costs Incurred						$4,795								$4,795
	PM Costs Recovered		$2,001	$2,001	$2,001	$2,001	$2,001	$1,170	$1,170	$1,170	$1,170	$1,170			$15,853
	NOx Costs Recovered							$1,170	$1,170	$1,170	$1,170	$1,170			$5,848
	Per Engine Cost		$12	$12	$12	$12	$11	$13	$13	$13	$12	$12			
50<=hp<75	Estimated US Sales	108,234	110,279	112,325	114,371	116,416	118,462	120,507	122,553	124,599	126,644	128,690	130,736	130,736	
	PM Costs Incurred	$5,470					$6,394								$11,863
	NOx Costs Incurred														$0
	PM Costs Recovered		$1,334	$1,334	$1,334	$1,334	$1,334	$1,559	$1,559	$1,559	$1,559	$1,559			$14,467
	NOx Costs Recovered														$0
	Per Engine Cost		$12	$12	$12	$11	$11	$13	$13	$13	$12	$12			
75<=hp<100	Estimated US Sales	79,159	80,659	82,158	83,657	85,157	86,656	88,155	89,654	91,154	92,653	94,152	95,652	95,652	
	PM Costs Incurred					$1,998									$1,998
	NOx Costs Incurred					$1,998		$1,998							$3,996
	PM Costs Recovered						$487	$487	$487	$487	$487				$2,437
	NOx Costs Recovered						$487	$487	$975	$975	$975	$487	$487		$4,873
	Per Engine Cost						$11	$11	$16	$16	$16	$5	$5		
100<=hp<175	Estimated US Sales	128,588	130,909	133,230	135,551	137,872	140,193	142,514	144,836	147,157	149,478	151,799	154,120	154,120	
	PM Costs Incurred					$2,652									$2,652
	NOx Costs Incurred					$2,652		$2,652							$5,304
	PM Costs Recovered						$647	$647	$647	$647	$647				$3,234
	NOx Costs Recovered						$647	$647	$1,294	$1,294	$1,294	$647	$647		$6,468
	Per Engine Cost						$9	$9	$13	$13	$13	$4	$4		
175<=hp<300	Estimated US Sales	71,749	73,163	74,577	75,991	77,405	78,819	80,233	81,647	83,061	84,475	85,889	87,303	87,303	
	PM Costs Incurred				$3,705										$3,705
	NOx Costs Incurred				$3,705			$3,705							$7,411
	PM Costs Recovered					$904	$904	$904	$904	$904					$4,519
	NOx Costs Recovered					$904	$904	$904	$1,807	$1,807	$904	$904	$904		$9,037
	Per Engine Cost					$23	$23	$23	$33	$33	$11	$11	$10		
300<=hp<600	Estimated US Sales	37,147	37,583	38,019	38,455	38,891	39,327	39,763	40,199	40,635	41,071	41,507	41,943	41,943	
	PM Costs Incurred				$2,325										$2,325
	NOx Costs Incurred				$2,325			$2,325							$4,650
	PM Costs Recovered					$567	$567	$567	$567	$567					$2,835
	NOx Costs Recovered					$567	$567	$567	$1,134	$1,134	$567	$567	$567		$5,670
	Per Engine Cost					$29	$29	$29	$42	$42	$14	$14	$14		
600<=hp<=750	Estimated US Sales	3,102	3,152	3,202	3,252	3,302	3,352	3,402	3,452	3,502	3,552	3,602	3,652	3,652	
	PM Costs Incurred				$327										$327
	NOx Costs Incurred				$327			$327							$654
	PM Costs Recovered					$80	$80	$80	$80	$80					$399
	NOx Costs Recovered					$80	$80	$80	$159	$159	$80	$80	$80		$797
	Per Engine Cost					$48	$48	$47	$69	$68	$22	$22	$22		
>750hp	Estimated US Sales	3,142	3,193	3,244	3,295	3,346	3,397	3,448	3,499	3,550	3,601	3,652	3,703	3,703	
	PM Costs Incurred				$727			$727							$1,453
	NOx Costs Incurred				$727			$727							$1,453
	PM Costs Recovered					$177	$177	$177	$354	$354	$177	$177	$177		$1,772
	NOx Costs Recovered					$177	$177	$177	$354	$354	$177	$177	$177		$1,772
	Per Engine Cost					$106	$104	$103	$203	$200	$98	$97	$96		
All hp	PM Costs Incurred	$20,014			$7,084	$4,650	$11,189	$727							$43,664
	NOx Costs Incurred				$7,084	$4,650	$4,795	$11,734							$28,263
	Total Costs Incurred	$20,014			$14,168	$9,300	$15,984	$12,461							$71,927
	PM Costs Recovered		$4,881	$4,881	$4,881	$6,609	$7,743	$5,591	$5,768	$5,768	$4,040	$2,906	$177		$53,246
	NOx Costs Recovered					$1,728	$2,862	$4,031	$6,893	$6,893	$5,165	$4,031	$2,862		$34,466
	Total Costs Recovered		$4,881	$4,881	$4,881	$8,337	$10,605	$9,622	$12,661	$12,661	$9,206	$6,937	$3,039		$87,712

6.2.2 Engine Variable Costs

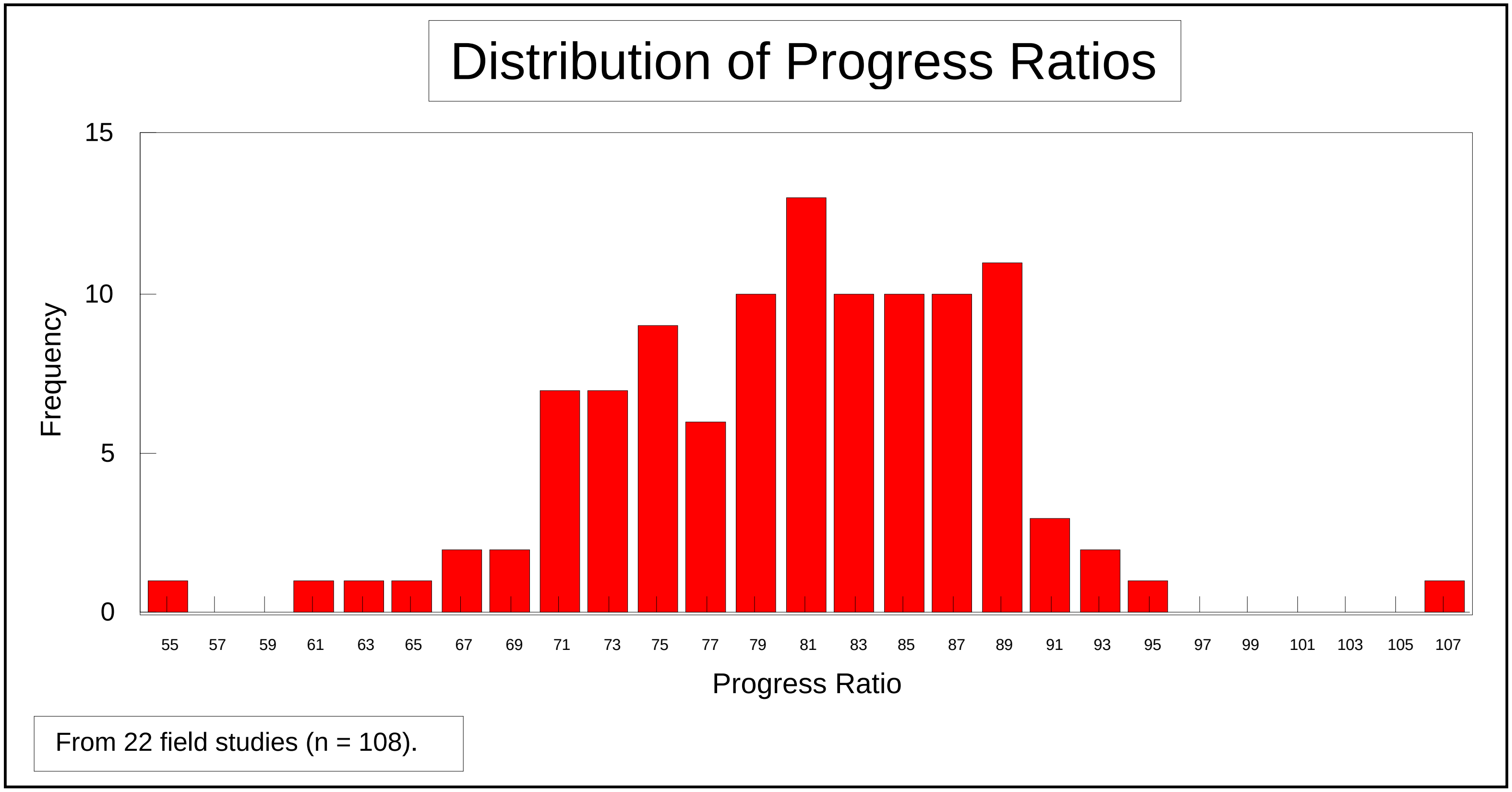
Engine variable costs are those costs for new hardware required to meet the proposed standards. In this section, we present our estimates of engine variable costs. Because of the wide variation of engine sizes in the nonroad market, we have chosen an approach that results not in a specific cost per engine for engines within a given horsepower range, but rather a set of equations that can be used to determine the variable costs for any engine provided its displacement and number of cylinders are known. As a result, we do not present here a cost of say, $50 per engine for engines in the 25 to 50 horsepower range, but instead present cost equations that can be used to determine the variable costs for an engine having, for example, a 0.5 liter engine with two cylinders. We believe this is a more comprehensive approach because it allows the reader to calculate costs more precisely for whatever engine(s) they are interested in. Further, variable costs can vary quite significantly within a given horsepower range unless the range is kept very small. To state an average variable cost for a range such as 175 to 300 horsepower is far less precise than what we present here. Using the equations presented here, we have estimated the engine variable costs for some specific example pieces of equipment; these estimates can be found in Section 6.5 of this Draft RIA.

The discussion here contains both near term and long term cost estimates. We believe there are factors that would cause variable hardware costs to decrease over time, making it appropriate to distinguish between near term and long term costs. Research in the costs of manufacturing has consistently shown that as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts, all of which allows them to lower the per-unit cost of production. These effects are often described as the manufacturing learning curve.[10]

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

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[11] The distribution of these progress ratios is shown in Figure 6.2-1. Except for one company that saw *increasing* costs as production continued, every study showed cost savings of at least five percent for every doubling of production volume. The average progress ratio for the whole data set falls between 81 and 82 percent. Other studies (Alchian 1963, Argote and Epple 1990, Benkard 1999) appear to support the commonly used p value of 80 percent, i.e., each doubling of cumulative production reduces the former cost level by 20 percent.

Figure 6.2-1
Distribution of Progress Ratios



Source: Dutton and Thomas, 1984.

The learning curve is not the same in all industries. For example, the effect of the learning curve seems to be less in the chemical industry and the nuclear power industry where a doubling of cumulative output is associated with 11% decrease in cost (Lieberman 1984, Zimmerman 1982). The effect of learning is more difficult to decipher in the computer chip industry (Gruber 1992).

EPA believes the use of the learning curve is appropriate to consider in assessing the cost impact of diesel engine emission controls. The learning curve applies to new technology, new manufacturing operations, new parts, and new assembly operations. Nonroad diesel engines currently do not use any form of NOx aftertreatment and have used diesel particulate filters in only limited application. Therefore, these are new technologies for nonroad diesel engines and will involve some new manufacturing operations, new parts, and new assembly operations beyond those anticipated in response to the HD2007 rule. Since this will be a new product, EPA believes this is an appropriate situation for the learning curve concept to apply. Opportunities to reduce unit labor and material costs and increase productivity (as discussed above) will be great. EPA believes a similar opportunity exists for the new control systems which will integrate the function of the engine and the emission control technologies. While all nonroad diesel engines beginning with Tier 3 compliance are expected to have the basic components of this system – advanced engine control modules (computers), advanced engine air management systems (cooled EGR, and variable geometry turbocharging), and advanced fuel systems including common rail systems – they will be applied in some new ways in response to the proposed Tier 4 standards. Additionally some new components will be applied for the first time. These new parts and new assemblies will involve new manufacturing operations. As manufacturers gain experience with these new systems, comparable learning is expected to occur with respect to unit labor and material costs. These changes require manufacturers to start new production procedures, which, over time, will improve with experience.

We have applied a p value of 80 percent beginning with the first year of introduction of any new technology. That is, variable costs were reduced by 20 percent for each doubling of cumulative production following the year in which the technology was first introduced in a given horsepower range of engines. This way, learning is applied at the start of 2013 for >175 horsepower engines and in 2014 for 75 to 175 horsepower engines because of the one year difference in their first year of compliance (i.e., the first year in which new technologies are introduced). Because the timing of the proposed standards follows implementation of the HD2007 rule, we have used the first stage of learning done via that rule as the starting point of learning for nonroad engines. In other words, the first learning phase in highway serves as the baseline level of learning for nonroad. We have then applied one additional learning step from there. In the HD2007 rule, we applied a second learning step following the second doubling of production that would occur at the end of the 2010 model year. We could have chosen that point as our baseline case for nonroad and then applied a single learning curve effect from there. Instead, we have chosen to use as our nonroad baseline the first learning step from the highway rule so that, with our single nonroad learning step, we have costs consistent with those costs estimated for highway diesel engines. In the long term, after applying the nonroad learning curve, our cost estimates for CDPFs and NOx adsorbers are the same for similar nonroad and highway diesel engines. This approach is consistent with the approach taken in our Tier 2 light-duty highway rule and the HD2007 rule for heavy-duty gasoline engines. There, compliance was being met through improvements to existing technologies rather than the development of new technologies. We argued in those rules that, with existing technologies, there would be less opportunity for lowering production costs. For that reason, we applied only one learning curve effect. The situation is similar for nonroad engines. Because the technologies will be, by the time they are introduced into the market, existing technologies, there would arguably be less opportunity for learning than there will be for the highway engines where the technologies are first introduced.

Another factor that plays into our near term and long term cost estimates is that for warranty claim rates. In our HD2007 rule, we estimated a warranty claim rate of one percent. Subsequent to that rule, we learned from industry that repair rates can be as much as two to three times higher during the initial years of production for a new technology relative to later years.[12] For this analysis, we have applied what we have learned in our warranty estimates by using a three percent warranty claim rate during the first two years and then one percent warranty claim rate thereafter. This difference in warranty claim rates, in addition to the learning effects discussed above, is reflected in the different long term costs relative to near term costs.

6.2.2.1 NOx Adsorber System Costs

The NOx adsorber system that we are anticipating would be applied for Tier 4 would be the same as that used for highway applications. In order for the NOx adsorber to function properly, a systems approach that includes a reductant metering system and control of engine A/F ratio is also necessary. Many of the new air handling and electronic system technologies developed in order to meet the Tier 2/3 nonroad engine standards can be applied to accomplish the NOx adsorber control functions as well. Some additional hardware for exhaust NOx or O_2 sensing and for fuel metering will likely be required. The cost estimates include a DOC for clean-up of hydrocarbon emissions that occur during NOx adsorber regeneration events.

We have used the same methodology to estimate costs associated with NOx adsorber systems as was used in our 2007 HD Highway rulemaking. The basic components of the NOx adsorber catalyst are well known and include the following material elements:

- an oxidation catalyst, typically platinum based;
- an alkaline earth metal to store NOx, typically barium based;
- a NOx reduction catalyst, typically rhodium based;
- a substrate upon which the catalyst washcoating is applied; and,
- a can to hold and support the substrate.

Examples of these material costs are summarized in Table 6.2-9 and represent costs to the engine manufacturers inclusive of supplier markups. The manufacturer costs shown in Table 6.2-9 (as well as Tables 6.2-11 and 6.2-16 for CDPF systems and DOCs, respectively) include additional markups to account for both manufacturer and dealer overhead and carrying costs. The application of overhead and carrying costs are consistent with the approach taken in the HD2007 rulemaking. In that rule, we used an approach to estimating the markup for catalyzed emission control technologies based on input from catalyst manufacturers. Specifically, we were told that device manufacturers could not markup the cost of the individual components within their products because those components consist of basic commodities (e.g., precious metals used in the catalyst could not be arbitrarily marked up because of their commodity status). Instead, manufacturing entities could only markup costs where they add a unique value to the product. In the case of catalyst systems, we were told that the underlying cost of precious metals, catalyst substrates, PM filter substrates, and canning materials were well known to both buyer and seller and no markup or profit recovery for those component costs could be derived by the catalyst manufacturer. In essence, these are components to which the supplier provides little value added engineering. The one component that was unique to each catalyst manufacturer (i.e., the component where they add a unique value) was the catalyst washcoat support materials. This mixture, of what is essentially specialized clays, serves to hold the catalytic metals in place and to control the surface area of the catalytic metals available for emission control. Although, the commodity price for the materials used in the washcoat is almost negligible (i.e. perhaps one or two dollars), we have estimated a substantial cost for washcoating based on the engineering value added by the catalyst manufacturer in this step. This is reflected in the costs presented for NOx adsorber systems, CDPF systems, and DOCs. This portion of the cost estimate – the washcoating – is where the catalyst manufacturer recovers the fixed cost for research and development as well as realizes a profit. To these manufacturer costs, we have added a four percent carrying costs to account for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. A dealer carrying cost in included to cover the cost of capital tied up in extra inventory. Considering input received from industry, we have adopted this approach of estimating individually the manufacturer and dealer markups in an effort to better reflect the value each entity adds at various stages of the supply chain.[13] Also included is our estimate of warranty costs for the NOx adsorber system.

Table 6.2-9. NOx Adsorber System Costs

	NOx Adsorber Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Engine Displacement (Liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Material and Component Costs								
Catalyst Volume (Liter)	0.59	2.25	5.88	7.05	11.46	27.00	30.45	51.75
Substrate	$3	$13	$33	$39	$64	$151	$170	$290
Washcoating and Canning	$14	$53	$139	$167	$271	$638	$720	$1,223
Platinum	$16	$62	$163	$195	$318	$748	$844	$1,434
Rhodium	$3	$11	$28	$34	$55	$129	$145	$246
Alkaline Earth Oxide, Barium	$1	$1	$1	$1	$1	$1	$1	$1
Catalyst Can Housing	$9	$9	$9	$9	$13	$19	$19	$19
Direct Labor Costs								
Estimated Labor hours	2	2	2	2	2	2	2	2
Labor Rate ($/hr)	$28	$28	$28	$28	$28	$28	$28	$28
Labor Cost	$42	$42	$42	$42	$42	$56	$56	$56
Labor Overhead @ 40%	$17	$17	$17	$17	$17	$22	$22	$22
Total Direct Costs to Mfr.	$105	$208	$432	$504	$780	$1,764	$1,977	$3,291
Warranty Cost -- Near Term (3% claim rate)	$9	$17	$34	$39	$60	$132	$148	$247
Mfr. Carrying Cost -- Near Term	$4	$8	$17	$20	$31	$71	$79	$132
Total Cost to Dealer -- Near Term	$119	$233	$483	$564	$872	$1,967	$2,204	$3,670
Dealer Carrying Cost -- Near Term	$4	$7	$14	$17	$26	$59	$66	$110
DOC for cleanup -- Near Term	$106	$134	$195	$214	$291	$468	$507	$749
Baseline Cost to Buyer -- Near Term	$228	$374	$692	$795	$1,189	$2,494	$2,778	$4,529
Cost to Buyer w/ Highway learning -- Near Term	$204	$326	$593	$679	$1,009	$2,089	$2,323	$3,773
Warranty Cost -- Long Term (1% claim rate)	$3	$6	$11	$13	$20	$44	$49	$82
Mfr. Carrying Cost -- Long Term	$4	$8	$17	$20	$31	$71	$79	$132
Total Cost to Dealer -- Long Term	$113	$222	$460	$537	$832	$1,879	$2,105	$3,505
Dealer Carrying Cost -- Long Term	$3	$7	$14	$16	$25	$56	$63	$105
DOC for cleanup -- Long Term	$100	$127	$185	$204	$277	$446	$483	$715
Baseline Cost to Buyer -- Long Term	$216	$355	$659	$757	$1,134	$2,381	$2,652	$4,325
Cost to Buyer w/ Highway learning -- Long Term	$193	$310	$564	$647	$962	$1,994	$2,218	$3,603
Cost to Buyer w/ Nonroad learning -- Long Term	$174	$273	$489	$558	$825	$1,684	$1,871	$3,026

We have estimated the cost of this system based on information from several reports.[14, 15, 16] The individual estimates and assumptions used to estimate the cost for the system are documented in the following subsections.

NOx Adsorber Catalyst Volume

The Engine Manufacturers Association was asked as part of a contractor work assignment to gather input from their members on likely technology solutions including the NOx adsorber catalyst.[17] The respondents indicated that the catalyst volume for a NOx adsorber catalyst could range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on today's washcoating technology. Based on current lean burn gasoline catalyst designs and engineering judgement, we have estimated that the NOx adsorber catalyst will be sized on average 1.5 times the engine displacement. This is consistent with the size of the NOx adsorber catalyst on the Toyota Avensis diesel passenger car (60 prototypes of a planned 2003 production car are being tested in Europe) which is sized at 1.4 times engine displacement.[18]

NOx Adsorber Substrate

The ceramic flow through substrates used for the NOx adsorber catalyst were estimated to cost $5.27 ($1999) per liter during our 2007 Highway rule. This cost estimate was based upon a relationship developed for current heavy-duty gasoline catalyst substrates.[19] We have converted that value to $5.60 ($2001) using the PPI for Motor Vehicle Parts and Accessories, Catalytic Convertors.[20]

NOx Adsorber Washcoating and Canning

We have estimated a "value-added" engineering and material product, called washcoating and canning, based on feedback from members of the Manufacturers of Emission Control Association (MECA).[21] By using a value added component that accounts for fixed costs (including R&D), overhead, marketing and profits from likely suppliers of the technology, we can estimate this fraction of the cost for the technology apart from the other components which are typically more widely available as commodities (e.g, precious metals and catalyst substrates). Based on conversations with MECA, we understand this element of the product to represent the catalyst manufacturer's value added and, therefore, their opportunity for markup. As a result, the washcoating and canning costs shown in Table 6.2-9 represent costs with manufacturer markups included.

NOx Adsorber Precious Metals

The total precious metal content for the NOx adsorber is estimated to be 50 g/ft^3 with platinum representing 90% of that total and rhodium representing 10%. The costs for rhodium and platinum used in this analysis are the 2002 average prices of $839 per troy ounce for rhodium and $542 per troy ounce for platinum, as reported by Johnson Matthey.[22]

NOx Adsorber Alkaline Earth Metal – Barium

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

NOx Adsorber Can Housing

The material cost for the can housing is estimated based on the catalyst volume plus 20% for transition cones, plus 20% for scrappage (material purchased but unused in the final product) and a price of $1.04 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2001.[23]

NOx Adsorber Direct Labor

The direct labor costs for the catalyst are estimated based upon an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[24]

NOx Adsorber Warranty

We have estimated both near term and long term warranty costs. Near term warranty costs are based on a three percent claim rate and an estimate of parts and labor costs per incident, while long term warranty costs are based on a one percent claim rate and an estimate of parts and labor costs per incident. The labor rate is assumed to be $50 per hour with four hours required per claim, and parts costs are estimated to be 2.5 times the original manufacturing cost for the component. The calculation of near term warranty costs for the 9 horsepower engine shown in Table 6.2-9 would be:

$$[(\$3 + \$14 + \$16 + \$3 + \$1 + \$9)(2.5) + (\$50)(4\text{hours})](3\%) = \$9.45$$

NOx Adsorber Manufacturer and Dealer Carrying Costs

The manufacturer's carrying cost was estimated at 4% of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3% of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.[25]

NOx Adsorber DOC for System Clean-up

Included in the costs for the NOx adsorber system are costs for a diesel oxidation catalyst (DOC) for clean-up of possible excess hydrocarbon emissions that might occur as a result of system regeneration (removal of stored NOx and reduction to N_2 and O_2). The methodology used to estimate DOC system costs is consistent with the methodology outlined here for NOx adsorber systems and is presented in Section 6.2.2.3, below. Important to note here is that the DOC costs shown in Table 6.2-9 are lower in the long term because of the lower warranty claim rate – 3 percent in the near term and one percent in the long term; learning effects, as discussed below, are not applied to DOC costs.

NOx Adsorber Cost Estimation Function

Using the example NOx adsorber costs shown in Table 6.2-9, we calculated a linear regression to determine the NOx adsorber system cost as a function of engine displacement. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total or per engine costs for NOx adsorber hardware. The functions calculated for NOx adsorber system costs used throughout this analysis are shown in Table 6.2-10. Note that Table 6.2-9 shows NOx adsorber system costs for engines below 75 horsepower. We do not anticipate any engines below 75 horsepower will apply NOx adsorber systems to comply with the proposed standards. Nonetheless, the costs shown were used to generate the equations shown in Table 6.2-10. Because of the linear relationship between engine displacement and NOx adsorber system size (and, therefore, cost), including the costs for these smaller engines does not inappropriately shift the cost equation downward.

Table 6.2-10
NOx Adsorber System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near Term Cost Function	\$105(x) + \$181	R^2=0.9998
Long Term Cost Function	\$84(x) + \$159	R^2=0.9997

Table 6.2-10 shows both a near term and a long term cost function for NOx adsorber system costs. The near term function incorporates the near term warranty costs determined using a three percent claim rate, while the long term function incorporates the long term warranty costs determined using a one percent claim rate. Additionally, the long term function incorporates learning curve effects for certain elements of the NOx adsorber system (i.e., learning effects were not applied to the DOC portion of the NOx adsorber system, for reasons discussed below). In the HD2007 rule, we applied two learning effects of 20 percent. Here, we have assumed one learning effect of 20 percent as a baseline level of learning; this represents learning done as a result of the HD2007 rule. After a single doubling of production (i.e., two years), we have then applied a single *nonroad* learning effect of 20 percent. Note that the equations shown in Table 6.2-10 include costs for a clean-up DOC; results generated using the DOC cost estimation equations presented in Table 6.2-14 should *not* be added to results generated using the equations in Table 6.2-10 to determine NOx adsorber system costs.

6.2.2.2 Catalyzed Diesel Particulate Filter Costs

As with the NOx adsorber system, the CDPF system that we are anticipating would be applied for Tier 4 would be the same as that used for highway applications, except that we are projecting that some form of active regeneration system would be employed as a backup to the passive regeneration capability of the CDPF. In order for the CDPF to function properly, a systems approach that includes a reductant metering system and control of engine A/F ratio is also necessary. Many of the new air handling and electronic system technologies developed in order to meet the Tier 2/3 nonroad engine standards can be applied to accomplish the CDPF control functions as well. Nonroad applications are expected to present challenges beyond those of highway applications with respect to implementing CDPFs. For this reason, we anticipate that some additional hardware beyond the diesel particulate filter itself may be required to ensure that CDPF regeneration occurs. For some engines this may be new fuel control strategies that force regeneration under some circumstances, while in other engines it might involve an exhaust system fuel injector to inject fuel upstream of the CDPF to provide necessary heat for regeneration under some operating conditions. The cost estimates for such a regeneration system are presented in section 6.2.2.3.

We have used the same methodology to estimate costs associated with CDPF systems as was used in our 2007 HD Highway rulemaking (although here, for nonroad engines, we have included costs for a regeneration system that was not part of the cost estimate in the 2007 HD rule). The basic components of the CDPF are well known and include the following material elements:

- an oxidation catalyst, typically platinum based;
- a substrate upon which the catalyst washcoating is applied and upon which PM is trapped;
- a can to hold and support the substrate; and,
- a regeneration system to ensure regeneration under all operating conditions (see section 6.2.2.3).

Examples of these material costs are summarized in Table 6.2-11 and represent costs to the engine manufacturers inclusive of supplier markups. The total direct cost to the manufacturer includes an estimate of warranty costs for the CDPF system. Hardware costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer's carrying cost was estimated to be four percent of the direct costs accounting for the capital cost of the extra inventory, and the incremental costs of insurance, handling, and storage. The dealer's carrying cost was marked up three percent reflecting the cost of capital tied up in inventory. Considering input received from industry, we have adopted this approach of estimating individually the manufacturer and dealer markups in an effort to better reflect the value added at each stage of the supply chain.[26]

Table 6.2-11. Catalyzed Diesel Particulate Filter (CDPF) System Costs

	Catalyzed Diesel Particulate Filter (CDPF) Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Average Engine Displacement (Liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Material and Component Costs								
Filter Volume (Liter)	0.59	2.25	5.88	7.05	11.46	27.00	30.45	51.75
Filter Trap	$37	$143	$375	$449	$730	$1,721	$1,940	$3,298
Washcoating and Canning	$14	$53	$139	$167	$271	$638	$720	$1,223
Platinum	$11	$42	$109	$130	$212	$499	$563	$956
Filter Can Housing	$7	$7	$7	$7	$11	$15	$15	$15
Differential Pressure Sensor	$48	$48	$48	$48	$48	$48	$96	$96
Direct Labor Costs	$0	$0	$0	$0	$0	$0	$0	$0
Estimated Labor hours	2	2	2	2	2	2	4	4
Labor Rate ($/hr)	$28	$28	$28	$28	$28	$28	$28	$28
Labor Cost	$56	$56	$56	$56	$56	$56	$112	$112
Labor Overhead @ 40%	$22	$22	$22	$22	$22	$22	$45	$45
Total Direct Costs to Mfr.	$195	$372	$756	$880	$1,350	$2,998	$3,490	$5,744
Warranty Cost -- Near Term (3% claim rate)	$12	$25	$54	$63	$98	$222	$253	$422
Mfr. Carrying Cost -- Near Term	$8	$15	$30	$35	$54	$120	$140	$230
Total Cost to Dealer -- Near Term	$215	$411	$840	$978	$1,502	$3,340	$3,882	$6,396
Dealer Carrying Cost -- Near Term	$6	$12	$25	$29	$45	$100	$116	$192
Savings by removing muffler	-$48	-$48	-$48	-$48	-$48	-$48	-$48	-$48
Baseline Cost to Buyer -- Near Term	$174	$376	$817	$959	$1,499	$3,393	$3,951	$6,540
Cost to Buyer w/ Highway learning -- Near Term	$139	$301	$654	$768	$1,199	$2,714	$3,161	$5,232
Warranty Cost -- Long Term (1% claim rate)	$4	$8	$18	$21	$33	$74	$84	$141
Mfr. Carrying Cost -- Long Term	$8	$15	$30	$35	$54	$120	$140	$230
Total Cost to Dealer -- Long Term	$207	$395	$804	$936	$1,436	$3,192	$3,714	$6,114
Dealer Carrying Cost -- Long Term	$6	$12	$24	$28	$43	$96	$111	$183
Savings by removing muffler	-$48	-$48	-$48	-$48	-$48	-$48	-$48	-$48
Baseline Cost to Buyer -- Long Term	$166	$359	$780	$916	$1,432	$3,240	$3,777	$6,250
Cost to Buyer w/ Highway learning -- Long Term	$132	$287	$624	$733	$1,145	$2,592	$3,022	$5,000
Cost to Buyer w/ Nonroad learning -- Long Term	$106	$230	$499	$586	$916	$2,074	$2,417	$4,000

CDPF Volume

During development of our HD2007 rule, the Engine Manufacturers Association was asked as part of a contractor work assignment to gather input from their members on catalyzed diesel particulate filters for heavy-duty highway applications.[27] The respondents indicated that the particulate filter volume could range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on their experiences at that time with cordierite filter technologies. The size of the diesel particulate filter is selected largely based upon the maximum allowable flow restriction for the engine. Generically, the filter size is inversely proportional to its resistance to flow (a larger filter is less restrictive than a similar smaller filter). In the HD2007 rule and here, we have estimated that the diesel particulate filter will be sized to be 1.5 times the engine displacement based on the responses received from EMA and on-going research aimed at improving filter porosity control to give a better trade-off between flow restrictions and filtering efficiency.

CDPF Substrate

In the HD2007 rule, we estimated that CDPFs would consist of a cordierite filter costing $30 per liter. For nonroad applications, we have assumed the use of silicon carbide filters costing double that amount, or $60 per liter. This cost is directly proportional to filter volume, which is proportional to engine displacement. This $60 value is then converted to $2001 using the PPI for Motor Vehicle Parts and Accessories, Catalytic Convertors.[28] The end result being a cost of $64 per liter.

CDPF Washcoating and Canning

These costs were done in a consistent manner as done for NOx adsorber catalyst systems as discussed above.

CDPF Precious Metals

The total precious metal content for catalyzed diesel particulate filters is estimated to be 30 g/ft^3 with platinum as the only precious metal used in the filter. As done for NOx adsorbers, we have used a price of $542 per troy ounce for platinum.

CDPF Can Housing

The material cost for the can housing is estimated based on the CDPF volume plus 20% for transition cones, plus 20% for scrappage (material purchased but unused in the final product) and a price of $1.04 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2001.[29]

CDPF Differential Pressure Sensor

We have assumed that the catalyzed diesel particulate filter system will require the use of a differential pressure sensor to provide a diagnostic monitoring function of the filter. A contractor report to EPA estimated the cost for such a sensor at $45.[30] A PPI adjusted cost of $48 per sensor has been used in this analysis.

CDPF Direct Labor

Consistent with the approach for NOx adsorber systems, the direct labor costs for the CDPF are estimated based upon an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[31]

CDPF Warranty

We have estimated both near term and long term warranty costs. Near term warranty costs are based on a three percent claim rate and an estimate of parts and labor costs per incident, while long term warranty costs are based on a one percent claim rate and an estimate of parts and labor costs per incident. The labor rate is assumed to be $50 per hour with two hours required per claim, and parts cost are estimated to be 2.5 times the original manufacturing cost for the component.

CDPF Manufacturer and Dealer Carrying Costs

Consistent with the approach for NOx adsorber systems, the manufacturer's carrying cost was estimated at 4% of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3% of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.[32]

Savings Associated with Muffler Removal

CDPF retrofits today are often incorporated in, or are simply replacements for, the muffler for diesel powered vehicles and equipment. One report noted that, "Often, the trap could be mounted in place of the muffler and had the same dimensions. Thus, rapid replacement was possible. The muffling effect was often even better."[33] We have assumed that applying a CDPF allows for the removal of the muffler due to the noise attenuation characteristics of the CDPF. We have accounted for this savings and have estimated a muffler cost of $48. The $48 estimate is an average for all engines, the actual savings would be higher for some and lower for others.

CDPF System Cost Estimation Function

Using the example CDPF costs shown in Table 6.2-11, we calculated a linear regression to determine the CDPF system cost as a function of engine displacement. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total or per engine costs for CDPF system hardware. The functions calculated for CDPF system costs used throughout this analysis are shown in Table 6.2-12.

Table 6.2-12
CDPF System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near term Cost Function	\$150(x) + \$71	R^2=0.9998
Long term Cost Function	\$114(x) + \$54	R^2=0.9998

The near term and long term costs shown in Table 6.2-12 change due to the different warranty claim rates and the application of a 20 percent learning curve effect.

6.2.2.3 CDPF Regeneration System Costs

The CDPF regeneration system is likely to include an O_2 sensor, a means for exhaust air to fuel ratio control (one or more exhaust fuel injectors or in-cylinder means), a temperature sensor and possibly a means to control mass flow through a portion of the catalyst system (e.g., for a "dual-bed" system). Incremental costs for a CDPF regeneration system, along with several other costs discussed below, were developed by ICF Consulting under contract to EPA. The results of that cost analysis are detailed in the report entitled, "Electronic Systems and EGR Costs for Nonroad Engines," which is contained in the docket for this rule.[34] The cost estimates developed by ICF for a CDPF regeneration system are summarized in Table 6.2-13.

Using these costs, we then estimated costs to the buyer using the same learning curve effects and warranty claim rate factors discussed above. These results are presented in Table 6.2-14.

Table 6.2-13.
CDPF Regeneration System – Costs to the Manufacturer

ICF Estimated Regeneration System Costs to Manufacturers (\$2001)								
Horsepower	20	35	80	150	250	400	650	1000
Displacement (L)	1	2	3	6	8	10	16	24
CDPF Regeneration System Costs	\$260	\$274	\$287	\$376	\$398	\$420	\$514	\$654

Table 6.2-14.
CDPF Regeneration System – Costs to the User

EPA Estimate of CDPF Regeneration System Costs ($2001)								
Horsepower	20	35	80	150	250	400	650	1000
Displacement (L)	1	2	3	6	8	10	16	24
CDPF Regeneration System Costs	$260	$274	$287	$376	$398	$420	$514	$654
Warranty Cost -- Near Term (3% claim rate)	$23	$24	$25	$31	$33	$34	$42	$52
Mfr. Carrying Cost (4%) -- Near Term	$10	$11	$11	$15	$16	$17	$21	$26
Total Cost to Dealer -- Near Term	$293	$308	$323	$422	$447	$471	$576	$733
Dealer Carrying Cost (3%) -- Near Term	$9	$9	$10	$13	$13	$14	$17	$22
Total Cost to Buyer -- Near Term	$302	$317	$333	$435	$460	$485	$593	$755
Warranty Cost -- Long Term (1% claim rate)	$8	$8	$8	$10	$11	$11	$14	$17
Mfr. Carrying Cost (4%)-- Long Term	$10	$11	$11	$15	$16	$17	$21	$26
Total Cost to Dealer -- Long Term	$278	$292	$307	$401	$425	$448	$548	$698
Dealer Carrying Cost (3%) -- Long Term	$8	$9	$9	$12	$13	$13	$16	$21
Subtotal	$286	$301	$316	$413	$437	$462	$565	$719
Total Cost to Buyer -- Long-Term w/ learning	$229	$241	$253	$331	$350	$369	$452	$575

As noted above, the CDPF regeneration system is expected to consist of an O_2 sensor, a temperature sensor, and probably a pressure sensor. The costs shown in Table 6.2-14 assume none of these sensors or other pieces of hardware exist and, more importantly, they assume the fuel control systems present in the engine are not capable of the sort of precise fuel control that could perform many of the necessary functions of the regeneration system without any additional hardware. For this reason, we consider the costs shown in Table 6.2-14 to be representative of the costs that would be incurred on an engine with an indirect injection (IDI) fuel system. For a direct injection (DI) fuel system, we expect that many of the functional capabilities for which costs were generated would be handled by the existing fuel system. For example, we are assuming that all DI engines will either convert to a fuel system capable of late injection or will already have a fuel system capable of late injection. Late injection is one of the primary means of using fuel strategies to force a CDPF regeneration event. Our cost estimates associated with conversion to such fuel systems are discussed below. Because the regeneration system costs for DI engines would be lower than those for an IDI engine, we have estimated that the regeneration system costs for a DI engine would be one-half those presented in Table 6.2-14.

Also, note that the air handling, electronic, and fuel system hardware used for backup active CDPF regeneration is expected to be used in common with the NOx adsorber regeneration system. We have accounted for these costs here (as a CDPF regeneration system) because CDPFs are required on a broader range of engines and, for many engines, earlier than are NOx adsorbers.

CDPF Regeneration System Cost Estimation Function

Using the example regeneration system costs shown in Table 6.2-14, we calculated a linear regression to determine the CDPF regeneration system cost as a function of engine displacement. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total costs for CDPF regeneration system hardware. The functions calculated for CDPF regeneration system costs used throughout this analysis are shown in Table 6.2-15.

Table 6.2-15
CDPF Regeneration System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

IDI Engine	Near term Cost Function	\$20(x) + \$289	R^2=0.9912
	Long term Cost Function	\$15(x) + \$219	R^2=0.9912
DI Engine	Near term Cost Function	\$10(x) + \$144	R^2=0.9912
	Long term Cost Function	\$7(x) + \$110	R^2=0.9912

Note that these costs – either the IDI or the DI costs, depending on the type of engine – would be incurred for any engine adding a CDPF. The near term and long term costs shown in Table 6.2-15 change due to the different warranty claim rates and the application of a 20 percent learning curve effect.

6.2.2.4 Diesel Oxidation Catalyst (DOC) Costs

The NOx adsorber regeneration and desulfation functions may produce undesirable by-products in the form of momentary increases in HC emissions or in odorous hydrogen sulfide (H_2S) emissions. In order to control these potential products, we have assumed that manufacturers may choose to apply a diesel oxidation catalyst (DOC) downstream of the NOx adsorber technology. The DOC would serve a “clean-up” function to oxidize any HC and H_2S emissions to more desirable products. As discussed below, for our cost analysis we have also estimated that engines <75 horsepower would add a DOC to comply with the 2008 PM standards, not to serve a “clean-up” function but rather to serve as the primary means of emission control.

Our estimates of DOC costs are shown in Table 6.2-16. The individual component costs for the DOC were estimated in the same manner as for the NOx adsorber systems and CDPF systems, as discussed above. However, no learning effects were applied to DOCs because we believe that DOCs have been manufactured for a long enough time period such that learning has already taken place.

Table 6.2-16.
Diesel Oxidation Catalyst (DOC) Costs

	Diesel Oxidation Catalyst Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Average Engine Displacement (Liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Material and Component Costs								
Catalyst Volume (liter)	0.39	1.50	3.92	4.70	7.64	18.00	20.30	34.50
Substrate	$2	$8	$22	$26	$43	$101	$114	$193
Washcoating and Canning	$63	$78	$110	$120	$159	$214	$227	$302
Platinum (5 g/ft3)	$1	$5	$12	$14	$24	$55	$63	$106
Catalyst Can Housing	$5	$5	$5	$5	$7	$16	$18	$30
Direct Labor Costs								
Estimated Labor hours	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Rate ($/hr)	$28	$28	$28	$28	$28	$28	$28	$28
Labor Cost	$14	$14	$14	$14	$14	$14	$14	$14
Labor Overhead @ 40%	$6	$6	$6	$6	$6	$6	$6	$6
Total Direct Costs to Mfr.	$91	$115	$168	$185	$252	$406	$440	$651
Warranty Cost -- Near Term (3% claim rate)	$8	$10	$14	$15	$20	$32	$35	$50
Mfr. Carrying Cost -- Near Term	$4	$5	$7	$7	$10	$16	$18	$26
Total Cost to Dealer -- Near Term	$103	$130	$189	$208	$282	$454	$492	$728
Dealer Carrying Cost -- Near Term	$3	$4	$6	$6	$8	$14	$15	$22
Total Cost to Buyer -- Near Term	$106	$134	$195	$214	$291	$468	$507	$749
Warranty Cost -- Long Term (1% claim rate)	$3	$3	$5	$5	$7	$11	$12	$17
Mfr. Carrying Cost -- Long Term	$4	$5	$7	$7	$10	$16	$18	$26
Total Cost to Dealer -- Long Term	$97	$123	$180	$198	$269	$433	$469	$694
Dealer Carrying Cost -- Long Term	$3	$4	$5	$6	$8	$13	$14	$21
Total Cost to Buyer -- Long Term	$100	$127	$185	$204	$277	$446	$483	$715

DOC Cost Estimation Function

Similar to what was done for NOx adsorber systems and CDPFs, we used the example costs shown in Table 6.2-16 to determine a cost function with engine displacement as the dependent variable. This way, the function could be applied to the wide array of engines in the nonroad fleet to determine the total or per unit costs for DOC hardware, whether that hardware be a stand alone emission control technology or as part of a NOx adsorber system. The cost functions for DOCs used throughout this analysis are shown in Table 6.2-17. Note that the NOx adsorber cost estimation equations shown in Table 6.2-10 include costs for a clean-up DOC; results generated using the DOC cost estimation equations presented in Table 6.2-17 should *not* be added to results generated using the equations in Table 6.2-10 to determine NOx adsorber system costs.

Table 6.2-17
DOC Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near term Cost Function	\$19(x) + \$117	R^2=0.9943
Long term Cost Function	\$18(x) + \$110	R^2=0.9943

6.2.2.5 Closed-Crankcase Ventilation (CCV) System Costs

Consistent with our HD2007 rule, we are proposing to eliminate the exemption that allows turbo-charged nonroad diesel engines to vent crankcase gases directly to the environment. Such engines are said to have an open crankcase system. We project that this requirement to close the crankcase on turbo charged engines would force manufacturers to rely on engineered closed crankcase ventilation systems that filter oil from the blow-by gases prior to routing them into either the engine intake or the exhaust system upstream of the CDPF. We expect these systems to be the same as those expected for highway engines and have estimated their costs in the same manner as done in our HD2007 rule. The estimated initial costs of these systems are as shown in Table 6.2-18. These costs are incurred only by turbo-charged engines.

Table 6.2-18.
Closed Crankcase Ventilation (CCV) System Costs

	Closed Crankcase Ventilation (CCV) System Costs ($2001)							
Horsepower	9 hp	33 hp	76 hp	150 hp	250 hp	503 hp	660 hp	1000 hp
Average Engine Displacement (Liter)	0.39	0.93	3.92	4.7	7.64	18	20.3	34.5
Cost to Manufacturer	$29	$30	$36	$37	$43	$62	$67	$94
Warranty Cost -- Near Term (3% claim rate)	$5	$5	$6	$6	$6	$8	$8	$10
Mfr. Carrying Cost -- Near Term	$1	$1	$1	$1	$2	$2	$3	$4
Total Cost to Dealer -- Near Term	$35	$36	$43	$44	$50	$72	$77	$107
Dealer Carrying Cost -- Near Term	$1	$1	$1	$1	$2	$2	$2	$3
Total Cost to Buyer -- Near Term	$36	$37	$44	$46	$52	$75	$80	$111
Warranty Cost -- Long Term (1% claim rate)	$2	$2	$2	$2	$2	$3	$3	$3
Mfr. Carrying Cost -- Long Term	$1	$1	$1	$1	$2	$2	$3	$4
Total Cost to Dealer -- Long Term	$32	$33	$39	$40	$46	$67	$72	$101
Dealer Carrying Cost -- Long Term	$1	$1	$1	$1	$1	$2	$2	$3
Cost to Buyer w/ Nonroad Learning -- Long Term	$26	$27	$32	$33	$38	$55	$59	$83

CCV Cost Estimation Function

As discussed above, an equation was developed as a function of engine displacement to calculate total or per unit CCV costs. These functions are shown in Table 6.2-19. Note that these costs would be incurred only by turbo-charged engines.

Table 6.2-19
CCV Costs as a Function of
Engine Displacement (x represents engine displacement in liters)

Near term Cost Function	$2(x) + $35	$R^2=1$
Long term Cost Function	$2(x) + $25	$R^2=1$

6.2.2.6 Variable Costs of Conventional Technologies for Engines Below 75 Horsepower and over 750 Horsepower

For the smaller horsepower categories, we have projected a different technology mix to enable compliance due to the different proposed standards. From a cost perspective, we have projected that engines would comply by either adding a DOC or by making some engine modifications resulting in engine-out emission reductions. Presumably, the manufacturer would choose the least costly approach that provided the necessary emission reduction. If engine-out modifications are less costly than a DOC, our estimate here is conservative. If the DOC proves to be less costly, then our estimate is representative of what most manufacturers would do. Therefore, we have assumed that, beginning in 2008, all engines below 75 horsepower add a DOC. Note that this is a conservative estimate in that we have assume this cost for all engines when, as discussed in Chapter 4, some engines <75 horsepower already meet the proposed PM standards. Our cost estimates for DOCs are presented above in Section 6.2.2.4.

As discussed in Chapter 4 of this Draft RIA, we have also projected that some engines in the 25 to 75 horsepower range would have to make changes to their engines to incorporate more conventional engine technology such as electronic common rail fuel injection to meet the demands of the newly added CDPF. These costs were assumed for direct injection (DI) engines. For indirect diesel injection (IDI) engines in this horsepower range, we believe that manufacturers would comply not through a fuel system upgrade to electronic common rail, but through the addition of a CDPF regeneration system to ensure regeneration of the CDPF. The costs for CDPF regeneration systems are discussed above in Section 6.2.2.3.

In the 25 to 50 horsepower range, we believe that all engines would add cooled EGR to meet the NOx standards proposed for that horsepower category. This is also true for engines >750 horsepower (note that engines >750 horsepower are also assumed to add the previously discussed exhaust emission control technologies – i.e., a NOx adsorber system, a CDPF system, and some sort of CDPF regeneration system).

All of these engines – those <75 horsepower and those >750 horsepower – are assumed to add CCV systems where those engines are turbocharged. The costs for CCV systems were presented in Section 6.2.2.5 above.

6.2.2.6.1 Electronic Common Rail Fuel Injection System Costs for DI Engines

Cost estimates for fuel injection systems were developed by ICF Consulting under contract to EPA. The results of cost analysis are detailed in the report entitled, “Electronic Systems and EGR Costs for Nonroad Engines,” which is contained in the docket for this rule.[35] Table 6.2-20 presents the costs to manufacturers as estimated by ICF for fuel injection systems.

Table 6.2-20
Fuel Injection System – Costs to Manufacturers

	Fuel System Costs ($2001)					
	Baseline System			New System		
Horsepower	20 hp	35 hp	80 hp	20 hp	35 hp	80 hp
Displacement (L)	1	2	3	1	2	3
# of Cylinders/Injectors	2	3	4	2	3	4
Type of Fuel System	Mech	Mech	ER	ECR	ECR	ECR
High Pressure Fuel Pump	$340	$340	$350	$340	$340	$350
Fuel Injectors (each)	$16	$16	$25	$80	$80	$80
Cost for Injectors (total)	$32	$48	$100	$160	$240	$320
Fuel Rail				$100	$100	$100
Computer			$300	$280	$280	$280
Sensors, Wiring, Bearings, etc.	$68	$82	$189	$231	$625	$639
Total Fuel System Cost	$440	$470	$939	$1,111	$1,205	$1,309
Incremental Cost				$671	$735	$370

Mech=Mechanical Fuel Injection; ER=Electronic Rotary Injection; ECR=Electronic Common Rail Injection

Note that engines in the 50 to 75 horsepower range (represented in Table 6.2-20 by the 80 horsepower engine) are assumed to have electronic rotary fuel injection systems as a baseline configuration while smaller engines are assumed to have mechanical fuel injection. On an incremental basis, the costs for common rail fuel injection are much lower when working from an electronic rotary baseline because the electronic fuel pump and the computer are already part of the system. This is the reason for the large difference in fuel system costs for the 80 horsepower engine relative to the 20 and 35 horsepower engines.

The costs shown in Table 6.2-20 show consistency for all elements across the horsepower range. This is because most of the cost elements – fuel pump, costs per injector, and a computer – have little to no relation to engine size or engine displacement. The primary cost element that changes for each of the example engines shown is that for the total cost of injectors. For this reason, the costs can be more easily understood by separating the per injector cost out from the rest of the system. This was done for the costs shown in Table 6.2-21, which also builds on the manufacturer costs shown in Table 6.2-21 to generate costs to the user in the same manner as done for other hardware system costs, as discussed above. We have broken out the fuel system costs in this manner so that a cost equation could be generated that would apply to all engines. Unlike the other cost equations we have generated, the cost equation for fuel systems uses the number of injectors (i.e., the number of cylinders) as the dependent variable rather than using engine displacement. This equation is presented below in Section 6.2.2.6.3.

Table 6.2-21
Incremental Fuel System Costs – Costs to the User

EPA Estimated Incremental Fuel System Costs for DI Engines ($2001)						
Horsepower	20		35		80	
Number of Cylinders (# of injectors)	2		3		4	
	per Injector	Remaining System	per Injector	Remaining System	per Injector	Remaining System
Cost to Manufacturer	$64	$543	$64	$543	$55	$150
Warranty Cost -- Near Term (3% claim rate)	$8	$44	$8	$44	$7	$14
Mfr. Carrying Cost (4%) -- Near Term	$3	$22	$3	$22	$2	$6
Total Cost to Dealer -- Near Term	$74	$608	$74	$608	$64	$170
Dealer Carrying Cost (3%) -- Near Term	$2	$18	$2	$18	$2	$5
Total Cost to Buyer -- Near Term	$77	$627	$77	$627	$66	$175
Warranty Cost -- Long Term (1% claim rate)	$3	$15	$3	$15	$2	$5
Mfr. Carrying Cost (4%)-- Long Term	$3	$22	$3	$22	$2	$6
Total Cost to Dealer -- Long Term	$69	$579	$69	$579	$60	$161
Dealer Carrying Cost (3%) -- Long Term	$2	$17	$2	$17	$2	$5
Subtotal	$71	$597	$71	$597	$61	$166
Total Cost to Buyer -- Long-Term w/ learning	$57	$477	$57	$477	$49	$132

Remaining System includes the fuel pump, fuel rail, computer, wiring, and necessary sensors.

Note that these costs are projected to be incurred only on 25 to 75 horsepower DI engines. Note also that, in determining aggregate variable costs for fuel injection systems, we have attributed half of the costs to the proposed Tier 4 standards. We have done this for two reasons: penetration of electronic fuel systems into the market, and user benefits associated with the new fuel systems. First, we are projecting that by 2008 some engines in the 25-75 hp range will already be equipped with electronic fuel systems independent of the standards contained in this Tier 4 proposal. This is due to the natural progression of electronic fuel systems currently available in larger power engines into some of the smaller power engines. During our discussions with some engine companies, they have indicated that the electronic fuel system technologies they intend to use to comply with the existing Tier 3 standards in the 50-100 hp range. These manufacturers have informed us that these electronic fuel systems will also be sold on engines in the 25-50 hp range for those engine product lines which are built on a common platform as engines above 50 hp. In addition, there are a number of end-user benefits associated with electronic fuel systems. These include better torque response, lower noise, easier servicing via on-board diagnostics, and better engine starting ability. Because we are not able to predict the precise level of penetration of electronic fuel systems, nor are we able to quantify the monetary value of the end-user benefits, we have accounted for these two effects by attributing half of the costs of the electronic fuel systems to the Tier 4 standards.

6.2.2.6.2 Cooled EGR System Costs

Cost estimates for cooled EGR systems were developed by ICF Consulting under contract to EPA. The results of cost analysis are detailed in the report entitled, “Electronic Systems and EGR Costs for Nonroad Engines,” which is contained in the docket for this rule.[36] The incremental manufacturer costs for cooled EGR systems are shown in Table 6.2-22.

Table 6.2-22
Cooled EGR System – Costs to Manufacturers

ICF Estimated Cooled EGR System Costs to Manufacturers ($2001)			
Horsepower	20	35	1000
Displacement (L)	1	2	24
EGR Cooler	$36	$63	$289
EGR Bypass	$15	$16	$30
Electronic EGR Valve	$14	$15	$88
EGR Total Cost to Manufacturer	$65	$94	$407

Building on these manufacturer costs, we estimated the costs to the user assuming the warranty claim rates and learning effects already discussed. These results are shown in Table 6.2-23.

Table 6.2-23
Cooled EGR System – Costs to the User

EPA Estimated Cooled EGR Costs ($2001)			
Horsepower	20	35	1000
Displacement (L)	1	2	24
Cost to Manufacturer	$65	$94	$407
Warranty Cost -- Near Term (3% claim rate)	$8	$10	$34
Mfr. Carrying Cost (4%) -- Near Term	$3	$4	$16
Total Cost to Dealer -- Near Term	$75	$108	$457
Dealer Carrying Cost (3%) -- Near Term	$2	$3	$14
Total Cost to Buyer -- Near Term	$78	$111	$471
Warranty Cost -- Long Term (1% claim rate)	$3	$3	$11
Mfr. Carrying Cost (4%)-- Long Term	$3	$4	$16
Total Cost to Dealer -- Long Term	$70	$101	$434
Dealer Carrying Cost (3%) -- Long Term	$2	$3	$13
Subtotal	$72	$104	$447
Total Cost to Buyer -- Long-Term w/ learning	$58	$83	$358

Note that we are projecting that only engines in the 25 to 50 horsepower range (in 2013) and engines >750 horsepower will need to add cooled EGR (consistent with the NOx phase-in from 2011 to 2014) to comply with the proposed standards. All of the costs associated with these systems have been attributed to compliance with the proposed standards (i.e., we have not attributed any costs to user benefits).

6.2.2.6.3 Conventional Technology Cost Estimation Functions

In the same manner as already described for exhaust emission control devices, we were able to calculate cost equations for cooled EGR systems. For fuel systems, rather than a linear regression, we simply expressed the fuel system costs as a function of the number of fuel injectors, and then added on the costs associated with the rest of the system. The rest of the system includes the fuel pump, the computer, wiring and sensors, which should not change relative to engine size or displacement. This way, the functions could be applied to the wide array of engines in the nonroad fleet to determine the total costs or per unit costs for this hardware. The cost estimation functions for these technologies are shown in Table 6.2-24.

Table 6.2-24
Costs for Conventional Technologies as a
Function of the Indicated Parameter (x represents the dependent variable)

Technology	Applicable Hp Range	Dependent Variable	Equation	R^2
Fuel System Costs – DI Only				
Near Term	25<=hp<50	# of cylinders	\$77(x) + \$627	—[a]
Long Term	25<=hp<50		\$57(x) + \$477	
Near Term	50<=hp<75		\$66(x) + \$175	—[a]
Long Term	50<=hp<75		\$49(x) + \$132	
Cooled EGR System				
Near Term	25<=hp<50; >750hp	displacement	\$17(x) + \$69	0.9986
Long Term	25<=hp<50; >750hp		\$13(x) + \$51	0.9986

[a] Not applicable, because a linear regression was not used.

6.2.3 Engine Operating Costs

We are projecting that a variety of new technologies will be introduced to enable nonroad engines to meet the proposed Tier 4 emissions standards. Primary among these are advanced emission control technologies and low-sulfur diesel fuel. The technology enabling benefits of low-sulfur diesel fuel are described in Chapter 4 of this Draft RIA. The incremental cost for low-sulfur fuel is described in Chapter 7 of this Draft RIA and is not presented here. The new emission control technologies are themselves expected to introduce additional operating costs in the form of increased fuel consumption and increased maintenance demands. Operating costs are estimated over the life of the engine and are expressed in terms of cents/gallon of fuel consumed. In Section 6.5 of this Draft RIA, we present these lifetime operating costs as a net present value (NPV) in 2001 dollars for several example pieces of equipment.

A note of clarification should be made here. In Chapter 8 of this Draft RIA, we present aggregate operating costs. Every effort is made to be clear what costs are related to increased costs for low sulfur fuel and what costs are related to maintenance costs and/or savings. The operating costs discussed in this section are only the latter of these – maintenance related costs and/or savings. Increased costs associated with the lowering of sulfur in nonroad diesel fuel are discussed in detail in Chapter 7 of this Draft RIA. The cent per gallon costs presented in Chapter 7, along with the cent per gallon costs and savings present here, are then combined with projected fuel volumes to generate the aggregate costs of our proposed fuel program.

Total operating costs, other than fuel, include the following elements: the change in maintenance costs associated with applying new emission controls to the engines; the change in maintenance costs associated with low sulfur fuel such as extended oil change intervals; the change in fuel costs associated with the incrementally higher costs for low sulfur fuel, and the change in fuel costs due to any fuel consumption impacts associated with applying new emission controls to the engines. This latter cost is attributed to the CDPF and its need for periodic regeneration which we estimate may result in a small fuel consumption increase as discussed in more detail below. Maintenance costs associated with the new emission controls on the engines are expected to increase since these devices represent new hardware and therefore new maintenance demands. Offsetting this cost increase will be a cost savings due to an expected increase in oil change intervals because low sulfur fuel would be far less corrosive than is current nonroad diesel fuel. Less corrosion would mean a slower acidification rate (i.e., less degradation) of the engine lubricating oil and, therefore, more operating hours between needed oil changes.

6.2.3.1 Operating Costs Associated with Oil Change Maintenance for New and Existing Engines

We estimate that reducing fuel sulfur to 500 ppm would reduce engine wear and oil degradation to the existing nonroad diesel fleet as well as locomotive and marine engines, and that a further reduction to 15 ppm sulfur would result in even greater reductions to the nonroad fleet. This reduction in wear and oil degradation would provide a savings to users of this equipment. The cost savings would also be realized by the owners of future nonroad engines that are subject to the standards in today’s proposal. As discussed below, these maintenance savings have been estimated to be greater than 3 cents per gallon for the use of 15 ppm sulfur fuel when compared to the use of today’s unregulated nonroad diesel fuel.

We have identified a variety of benefits from the low-sulfur diesel fuel. These benefits are summarized in Table 6.2-25.

Table 6.2-25.
Engine Components Potentially Affected by Lower Sulfur Levels in Diesel Fuel

Affected Components	Effect of Lower Sulfur	Potential Impact on Engine System
Piston Rings	Reduced corrosion wear	Extended engine life and less frequent rebuilds
Cylinder Liners	Reduced corrosion wear	Extended engine life and less frequent rebuilds
Oil Quality	Reduced deposits, reduced acid build-up, and less need for alkaline additives	Reduce wear on piston ring and cylinder liner and less frequent oil changes
Exhaust System (tailpipe)	Reduced corrosion wear	Less frequent part replacement
Exhaust Gas Recirculation System	Reduced corrosion wear	Less frequent part replacement

The monetary value of these benefits over the life of the equipment will depend upon the length of time that the equipment operates on low-sulfur diesel fuel and the degree to which engine and equipment manufacturers specify new maintenance practices and the degree to which equipment operators change engine maintenance patterns to take advantage of these benefits. For equipment near the end of its life in the 2008 time frame, the benefits will be quite small. However, for equipment produced in the years immediately preceding the introduction of 500 ppm sulfur fuel, the savings would be substantial. Additional savings would be realized in 2010 when the 15 ppm sulfur fuel would be introduced

We estimate the single largest savings would be the impact of lower sulfur fuel on oil change intervals. We have estimated the oil change interval extension that would be realized by the introduction of 500 ppm sulfur fuel in 2007, as well as the additional oil extension that would be realized with the introduction of 15 ppm sulfur nonroad diesel fuel in 2010. These estimates are based on our analysis of publically available information from nonroad engine manufacturers. Due to the wide range of diesel fuel sulfur which today's nonroad engines may see around the world, engine manufacturers specify different oil change intervals as a function of diesel sulfur levels. We have used these data as the basis for our analysis. Taken together, when compared to today's relatively high nonroad diesel fuel sulfur levels, we estimate the use of 500 ppm sulfur fuel would enable an oil change interval extension of 31 percent, while 15 ppm sulfur fuel would enable an oil change interval extension of 35 percent relative to today's products.[37]

We present here a fuel cost savings attributed to the oil change interval extension in terms of a cents per gallon operating cost. We estimate that an oil change interval extension of 31 percent, as would be enabled by the use of 500 ppm sulfur fuel in 2007, results in a weighted fuel operating costs savings of 3.0 cents per gallon for the nonroad fleet. We project an additional weighted cost savings of 0.3 cents per gallon for the oil change interval extension which would be enabled by the use of 15 ppm sulfur beginning in 2010. Thus, for the nonroad fleet as a whole, beginning in 2010, nonroad equipment users can realize an operating cost savings of 3.3

cents per gallon compared to today's engine. For a typical 100 horsepower nonroad engine, this represents a net present value lifetime savings of more than $500. Table 6.2-26 shows the calculation of cent per gallon savings for various horsepower segments of the nonroad fleet.

Table 6.2-26. Oil Change Maintenance Savings for Existing and New Nonroad, Locomotive, and Marine Engines ($2001)

Oil Change Savings due to Low S	Units	Nonroad Engines									
Rated Power	hp	0-25	25-50	50-75	75-175	175-300	300-600	600-750	750+	Locomotive	Marine
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.38996	0.367	0.367	0.367	0.367	0.367	0.367
Fuel Density	lbm/gallon	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Population Weighted Avg. Horsepower	hp	18	37	67	113	223	381	717	1263	1263	1263
Population Weighted Avg. Activity	hrs/year	524	579	707	696	525	585	931	921	921	921
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.44	0.47	0.56	0.56	0.55	0.54	0.54	0.54
Sump Oil Capacity	L	1.75	3.59	6.50	10.96	21.63	36.96	69.55	122.51	122.51	122.51
Base Oil Change Interval -- 3000 ppm S	hrs	250	250	250	250	250	250	250	250	250	250
Control Oil Change Interval -- 500 ppm S	hrs	327.5	327.5	327.5	327.5	327.5	327.5	327.5	327.5	327.5	327.5
Labor Cost Per Oil Change	$	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$100.00	$100.00	$100.00
Cost of Oil Per Oil Change	$	$3.49	$7.18	$13.00	$21.92	$43.26	$73.91	$139.10	$245.02	$245.02	$245.02
Cost of Oil Filter Per Oil Change		$18.00	$18.00	$18.00	$18.00	$35.00	$35.00	$35.00	$70.00	$70.00	$70.00
Total Cost Per Oil Change	$	$71.49	$75.18	$81.00	$89.92	$128.26	$158.91	$224.10	$415.02	$415.02	$415.02
Fuel Consumption in 3000 ppm Oil Interval	gallons	106	234	424	729	1614	2757	5096	8813	8813	8813
Fuel Consumption in 500 ppm Oil Interval	gallons	139	306	555	955	2114	3612	6676	11546	11546	11546
Oil Change Cost/Gallon fuel in 3000 ppm Interval	$/gallon	$0.67	$0.32	$0.19	$0.12	$0.08	$0.06	$0.04	$0.05	$0.05	$0.05
Oil Change Cost/Gallon fuel 500 ppm Interval	$/gallon	$0.51	$0.25	$0.15	$0.09	$0.06	$0.04	$0.03	$0.04	$0.04	$0.04
Cost Differential -- 3000 to 500 ppm S	$/gallon	$0.160	$0.076	$0.045	$0.029	$0.019	$0.014	$0.010	$0.011	$0.011	$0.011
Control Oil Change Interval -- 15 ppm S	hrs	337.5	337.5	337.5	337.5	337.5	337.5	337.5	337.5	337.5	337.5
Labor Cost Per Oil Change	$	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$100.00	$100.00	$100.00
Cost of Oil Per Oil Change	$	$3.49	$7.18	$13.00	$21.92	$43.26	$73.91	$139.10	$245.02	$245.02	$245.02
Cost of Oil Filter Per Oil Change		$18.00	$18.00	$18.00	$18.00	$35.00	$35.00	$35.00	$70.00	$70.00	$70.00
Total Cost Per Oil Change	$	$71.49	$75.18	$81.00	$89.92	$128.26	$158.91	$224.10	$415.02	$415.02	$415.02
Fuel Consumption in 500 ppm Oil Interval	gallons	139	306	555	955	2114	3612	6676	11546	11546	11546
Fuel Consumption in 15 ppm Oil Interval	gallons	143	316	572	984	2179	3722	6880	11898	11898	11898
Oil Change Cost/Gallon fuel in 500 ppm Interval	$/gallon	$0.51	$0.25	$0.15	$0.09	$0.06	$0.04	$0.03	$0.04	$0.04	$0.04
Oil Change Cost/Gallon fuel in 15 ppm Interval	$/gallon	$0.50	$0.24	$0.14	$0.09	$0.06	$0.04	$0.03	$0.03	$0.03	$0.03
Cost Differential -- 500 to 15 ppm S	$/gallon	$0.015	$0.007	$0.004	$0.003	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
Cost Differential -- 3000 to 15 ppm S	$/gallon	$0.175	$0.083	$0.050	$0.032	$0.021	$0.015	$0.011	$0.012	$0.012	$0.012
Fuel Use Weightings	% total	2.4%	5.1%	14.0%	26.3%	23.0%	17.7%	4.1%	7.5%		

Notes to table 6.2-26:

(1) Oil change intervals are from William Charmley memo to docket.[38]

(2) Labor costs are from ICF Consulting under contract to EPA.[39]

(3) Oil use estimates are based on sump volumes scaled to engine displacement and, as such, they show differences for each horsepower category. The labor and filter costs are average costs across a broad range of horsepower sizes and, as such, may overstate the cost for some engines while understating the costs for others.

Table 6.2-26 shows oil change maintenance intervals for both the 500 ppm fuel and the 15 ppm fuel. The existing and new nonroad fleets would realize the savings associated with the 500 ppm fuel for the years 2007 through 2010, and the the savings associated with the 15 ppm fuel program for the years 2010 and beyond. The locomotive and marine fleet would realize the savings associated with the 500 ppm fuel for the years 2007 and beyond. The oil change maintenance savings for locomotive and marine engines associated with the 15 ppm fuel are shown in Table 6.2-26 for informational purposes only; these values are used only in our analysis of alternative program options presented in Chapter 12 of this Draft RIA. Note that the weighted values of 3.0 cents per gallon and 3.3 cents per gallon are calculated by weighting the cent per gallon for each horsepower category by the fuel use weighting shown in the table.

The savings shown in Table 6.2-26 would occur without additional new cost to the equipment owner beyond the incremental cost of the low-sulfur diesel fuel, although these savings are dependent on changes to existing maintenance schedules. Such changes seem likely given the magnitude of the savings. We have not estimated the value of the savings from the other benefits listed in Table 6.2-25 and, therefore, we believe the 3.3 cents per gallon savings is conservative as it only accounts for the impact of low sulfur fuel on oil change intervals.

Operating costs associated with oil change maintenance are attributed evenly between NOx and PM control.

6.2.3.2 Operating Costs Associated with CDPF Maintenance for New CDPF-Equipped Engines

The maintenance demands associated with the addition of new CDPF hardware were discussed in Chapter 4.1.1.3.4. To be conservative, we have used a maintenance interval of 3,000 hours for engines below 175 horsepower and 4,500 hours for engines above 175 horsepower, both of which are the minimum allowable maintenance intervals specified in our regulations (i.e., manufacturers are precluded by regulation from requiring more frequent maintenance, and we believe they may require less frequent maintenance than these minimum allowable maintenance intervals). We have estimated costs associated with the maintenance at $65 for engines up to 600 horsepower and $260 per event for engines above 600 horsepower. The calculations for CDPF maintenance are shown in Table 6.2-27. Weighting the savings shown by the fuel use weightings shown in the table, we can calculate these costs as 0.6 cents per gallon which would be incurred only by new engines equipped with a CDPF.[40]

Operating costs associated with CDPF maintenance are attributed only to PM control.

Table 6.2-27
CDPF Maintenance Costs for New CDPF-Equipped Engines ($2001)

PM Filter Maintenance Costs	Units	Nonroad Engines							
Rated Power	hp	0-25	25-50	50-75	75-175	175-300	300-600	600-750	750+
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.38996	0.367	0.367	0.367	0.367
Fuel Density	lbm/gallon	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Population Weighted Avg. Horsepower	hp	18	37	67	113	223	381	717	1263
Population Weighted Avg. Activity	hrs/year	524	579	707	696	525	585	931	921
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.44	0.47	0.56	0.56	0.55	0.54
Filter Maintenance Interval	hours	3,000	3,000	3,000	3,000	4,500	4,500	4,500	4,500
Filter Maintenance Cost Materials	$/event	$0	$0	$0	$0	$0	$0	$0	$0
Filter Maintenance Labor	$/event	$65	$65	$65	$65	$65	$65	$130	$260
Total Filter Maintenance Cost per event	$/event	$65	$65	$65	$65	$65	$65	$130	$260
Fuel Use Between Maintenance Interval	gallons/period	1,272	2,807	5,082	8,751	29,048	49,629	91,728	158,642
Maintenance Cost	$/gallon	$0.051	$0.023	$0.013	$0.007	$0.002	$0.001	$0.001	$0.002
Fuel Use Weightings	% total	2.4%	5.1%	14.0%	26.3%	23.0%	17.7%	4.1%	7.5%

Labor costs are from ICF Consulting under contract to EPA.[41]

6.2.3.3 Operating Costs Associated with Fuel Economy Impacts on New Engines

6.2.3.3.1 What Would the Fuel Economy Impacts Be?

The high efficiency emission control technologies expected to be applied to meet the PM standards for engines greater than 25 horsepower and the NOx standards for engines greater than 75 horsepower involve wholly new system components integrated into engine designs and calibrations and, as such, may be expected to change the fuel consumption characteristics of the overall engine design. After reviewing the likely technology options available to the engine manufacturers, we believe that the integration of the engine and exhaust emission control systems into a single synergistic emission control system will lead to nonroad engines which can meet demanding emission control targets with only a small impact on fuel consumption. Technology improvements have historically eliminated these marginal impacts in the past and it is our expectation that this kind of continuing improvement will eliminate the modest impact estimated here. However, because we cannot project the timeframe for this improvement to be realized, we have conservatively included this impact in our cost estimates for the full period of the program.

6.2.3.3.1.1 CDPF Systems and Fuel Economy

Diesel particulate filters are anticipated to provide a step-wise decrease in diesel particulate (PM) emissions by trapping and oxidizing the diesel PM. The trapping of the very fine diesel PM is accomplished by forcing the exhaust through a porous filtering media with extremely small openings and long path lengths.[F] This approach results in filtering efficiencies for diesel PM greater than 90 percent but requires additional pumping work to force the exhaust through

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[F] Typically, the filtering media is a porous ceramic monolith or a metallic fiber mesh. We refer to it as a “filter trap” in Table 6.2-11.

these small openings. The impact of this additional pumping work on fuel consumption is dependent on engine operating conditions. At low exhaust flow conditions (i.e., low engine load, low turbocharger boost levels), the impact is so small that it can typically not be measured, while at very high load conditions, with high exhaust flow conditions, the fuel economy impact can be as large as one to two percent.[42,43] We have estimated that the average impact of this increased pumping work will be equivalent to an increase fuel consumption of approximately one percent.[44]

Under conditions typical of much of nonroad engine operation, the soot stored in the PM filter will be regenerated passively using the heat of the exhaust gas promoted by catalyst materials. We have performed an analysis of the expected exhaust temperatures for a number of typical in-use operating cycles in Chapter 4.1.3 of this draft RIA. That analysis shows that for a many nonroad engines passive regeneration can be expected. Under some conditions including very low ambient temperatures, or extended low load operation, the exhaust temperature of the engine may not be hot enough to ensure complete passive regeneration. To address this situation, we believe that some manufacturers will need to employ active backup regeneration systems that provide supplemental heat to initiate regeneration as discussed in Chapter 4.1 of this Draft RIA and, as explained in Section 6.2.2.3, we are costing active regeneration systems for all engines using a CDPF system. We have estimated a cost for active regeneration systems for all engines even though CDPF systems on many nonroad engines are expected to regenerate passively. We have done this because we think that it is unlikely that nonroad engine manufacturers will be able to accurately predict which engines will be operated in a manner conducive to passive regeneration and which engines will require periodic active regeneration. There will be no fuel economy impact for nonroad engines that have an active regeneration technology but which in-use experience passive regeneration. Examples of active PM filter systems today, that do not benefit from low sulfur diesel fuel, nor catalytic coatings to promote regeneration, require additional fuel supplementation of approximately two percent for active filter regeneration.[45] Given the clean diesel fuel proposed in this rulemaking, the ability to use catalytic coatings to promote soot oxidation and the fact that many kinds of nonroad equipment are expected to be operated in a manner such that passive regeneration will occur, we believe that the average fuel economy impact of the backup regeneration systems will be no larger than one percent.

We have projected that engines in the horsepower category from 25 hp to 75 horsepower will comply with the PM standard of 0.02 g/bhp-hr using a CDPF system including a backup active regeneration system. The NOx control systems expected in this horsepower category are not advanced catalyst based systems and, as such, have limited ability to recover fuel economy through timing advance or other in-cylinder NOx control strategies as discussed below. Therefore, we project that a two percent fuel economy impact (i.e. one percent due to backpressure and one percent due to use of backup regeneration systems) will be realized by engines in this category from 25 hp to 75 hp. We believe that it is likely that in the long term this impact will be recovered through continuing technology refinement as has historically happened. However, to be conservative in our cost analysis, we have included this two percent impact for the entire duration of the program.

For engines in the horsepower category below 25 hp we have projected no need to use CDPF technologies to comply with the proposed PM standard. Therefore, no fuel consumption impact from the CDPF is estimated for this category.

We believe all engines in the horsepower categories above 75 hp will use integrated NOx and PM control technologies to comply with the emission standards proposed today. The advanced catalyst based emission control technology that we project industry will use to comply with the proposed NOx standard offers the opportunity to improve fuel economy as described in the following section. Based on those projected improvements, we have estimated that the net impact on fuel consumption for engines greater than 75 hp due to the CDPF technology and the NOx technology to be one percent. Future technology improvements are likely to recover this fuel consumption impact; however, to be conservative in our cost analysis, we have assumed that a one percent fuel consumption impact persists for the period of the emission control program.

6.2.3.3.1.2 NOx Control and Fuel Economy

NOx adsorbers are expected to be the primary NOx control technology introduced in order to provide the reduction in NOx emissions for engines greater than 75 hp. NOx adsorbers work by storing NOx emissions under fuel lean operating conditions (normal diesel engine operating conditions) and then by releasing and reducing the stored NOx emissions over a brief period of fuel rich engine operation. This brief periodic NOx release and reduction step is directly analogous to the catalytic reduction of NOx over a gasoline three-way catalyst. In order for this catalyst function to occur the engine exhaust constituents and conditions must be similar to normal gasoline exhaust constituents. That is, the exhaust must be fuel rich (devoid of excess oxygen) and hot (over 250ºC). Although it is anticipated that nonroad diesel engines like on-highway diesel engines can be made to operate in this way, it is anticipated that fuel economy while operating under these conditions will be worse than normal. This increase in fuel consumption can be minimized by carefully controlling engine air-to-fuel (A/F) ratios using the control systems we anticipate will be used to meet the Tier 3 emission standards. The lower the engine A/F ratio, the lower the amount of fuel which must be added in order to give rich conditions. In the ideal case where the engine A/F ratio is at stoichiometry, and additional fuel is required only as a NOx reductant the fuel economy penalty is virtually zero. We are projecting that practical limitations on engine A/F control will mean that the NOx adsorber release and reduction cycles will lead to a one percent decrease in the engine fuel economy.[46] We estimate that this fuel economy impact can be regained through optimization of the engine-PM trap-NOx adsorber system, as discussed below.

In addition to the NOx release and regeneration event, another step in NOx adsorber operation may affect fuel economy. As discussed earlier, NOx adsorbers are poisoned by sulfur in the fuel even at the low sulfur levels proposed today. As discussed in chapter 4 of this Draft RIA, the sulfur poisoning of the NOx adsorber can (and must) be reversed through a periodic “desulfation” event. The desulfation of the NOx adsorber is accomplished in a similar manner to the NOx release and regeneration cycle described above. However it is anticipated that the desulfation event will require extended operation of the diesel engine at rich conditions.[47] This rich operation will, like the NOx regeneration event, require an increase in the fuel consumption rate and will cause an associated decrease in fuel economy. This loss in fuel consumption is directly proportional to the amount of sulfur in diesel fuel. The frequency of desulfation is therefore a function of the fuel sulfur level and the fuel consumption rate. Since the desulfation frequency and the associated fuel consumption impacts are proportional only to fuel rate and to fuel sulfur levels, the projected fuel consumption impacts at 15 ppm sulfur are the same for on-highway and nonroad diesel engines. With a 15 ppm fuel sulfur cap, we are projecting that fuel consumption for desulfation would increase by no more than one percent, which we believe can be regained through optimization of the engine-CDPF-NOx adsorber system as discussed below.

While NOx adsorbers require non-power producing consumption of diesel fuel in order to function properly and, therefore, have an impact on fuel economy, they are not unique among NOx control technologies in this way. In fact NOx adsorbers are likely to have a very favorable NOx to fuel economy trade-off when compared to our projected Tier 3 NOx control technologies, cooled EGR and injection timing retard. EGR requires the delivery of exhaust gas from the exhaust manifold to the intake manifold of the engine and causes a decrease in fuel economy for two reasons. The first of these reasons is that a certain amount of work is required to pump the EGR from the exhaust manifold to the intake manifold; this necessitates the use of intake throttling or some other means to accomplish this pumping. The second of these reasons is that heat in the exhaust, which is normally partially recovered as work across the turbine of the turbocharger, is instead lost to the engine coolant through the cooled EGR heat exchanger. In the end, cooled EGR is approximately 50 percent effective at reducing NOx below the current Tier 2 NOx levels. Injection timing retard is another strategy that can be employed to control NOx emissions. By retarding the introduction of fuel into the engine, and thus delaying the start of combustion, both the peak temperature and pressure of the combustion event are decreased; this lowers NOx formation rates and, ultimately, NOx emissions. Unfortunately, this also significantly decreases the thermal efficiency of the engine (lowers fuel economy) while also increasing PM emissions. As an example, retarding injection timing eight degrees can decrease NOx emissions by 45 percent, but this occurs at a fuel economy penalty of more than seven percent.[48]

Nonroad Tier 2 diesel engines rely primarily on charge-air-cooling and injection timing control (retarding injection timing) in order to meet the Tier 2 NOx+NMHC emission standard. For Tier 3 compliance, we expect that engine manufacturers will use a combination of cooled EGR and injection timing control to meet the NOx standard. Because of the more favorable fuel economy trade-off for NOx control with EGR when compared to timing control, we have forecast that less reliance on timing control will be needed in Tier 3, when compared to Tier 2. Therefore, fuel economy will not be changed even at this lower NOx level. Similarly for the 25-50 hp engines which would need to meet a 3.3 g/bhp-hr Tier 4 NOx emission limit under today's proposal, we believe that there will be no change in fuel consumption due to the NOx standard. NOx adsorbers have a significantly more favorable NOx to fuel economy trade-off when compared to cooled EGR or timing retard.[49] We expect NOx adsorbers to be able to accomplish a greater than 90 percent reduction in NOx emissions, while themselves consuming significantly less fuel than that lost through alternative NOx control strategies such as retarded injection timing.[G] Therefore, we expect manufacturers to take full advantage of the NOx control capabilities of the NOx adsorber and project that they will decrease reliance on the more expensive (from a fuel economy standpoint) technologies, especially injection timing retard. We would, therefore, predict that the fuel economy impact currently associated with NOx control from timing retard will be decreased by at least three percent. In other words, through the application of advanced NOx emission control technologies, which are enabled by the use of low sulfur diesel fuel, we expect the NOx trade-off with fuel economy to continue to improve significantly when compared to today's technologies. This will result in both much lower NOx emissions, and potentially overall improvements in fuel economy. Improvements could easily offset the fuel consumption of the NOx adsorber itself and, in addition, at least half of the fuel economy impact projected to result from the application of the CDPF technology. Consequently, we are projecting a one percent fuel economy impact to result from this rule for engines in the horsepower categories above 75 hp.

6.2.3.3.1.3 Fuel Economy Impacts for Engines without Advanced Emission Control Technologies (engines <25 horsepower)

The emission standard proposed today for engines below 25 hp does not change the NOx emission standard from the current Tier 2 level. The PM standard, however, is reduced by almost 50%. We believe that this significant PM reduction will be realized through improvements in combustion system design, improvements in fuel system design and utilization and through the use of diesel oxidation catalysts (DOCs). DOCs are expected to have no measurable effect on fuel consumption. However, changes to the engine designed to reduce PM emissions could lead to a reduction in fuel consumption, at least for direct injected diesel engines. The potential range for improved fuel economy for engines of this size is unknown but experience with changes to engine design that improve combustion and reduce PM suggest that the improvement could be significant. However, because of the difficulty in projecting the future ratio of direct-injected and indirect-injected diesel engines for this portion of the nonroad market and the first order affect that this ratio has on average fleet consumption we have not attempted to account for this potential fuel economy improvement in our cost analysis. Therefore, no change in fuel consumption is estimated in our cost analyses for engines with rated power below 25 hp.

6.2.3.3.2 Costs Associated with these Fuel Economy Impacts

To calculate the costs associated with these fuel economy impacts, we have used a diesel fuel price, minus taxes, of 60 cents per gallon. To that, we have added the incremental cost per gallon

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[G] EPA has estimated the fuel consumption rate for NOx regeneration and desulfation of the NOx adsorber as approximately 2 percent of total engine fuel consumption. This differs from an EPA contractor report by EF&EE which estimates the total consumption as approximately 2.5% of total fuel consumption. Additionally the contractor's estimate of NOx adsorber efficiency ranges from 80-90 percent, while EPA believes over 90 percent control is possible as discussed fully in Chapter 4 of this draft RIA.

for 15 ppm fuel where appropriate. These incremental fuel costs are discussed in Chapter 7 of this Draft RIA as 4.8 cents per gallon. This increased operating cost – 60 cents plus 4.8 cents – is applied to only those gallons of fuel consumed in engines equipped with technologies for which a fuel economy impact would be realized. For 25 to 50 horsepower engines, where we estimate a two percent impact, the incremental cost would be 1.3 cents per gallon (2%*64.8 cents/gallon). For >75 horsepower engines, where we estimate a one percent fuel economy impact, the incremental cost would be 0.65 cents per gallon.

Operating costs associated with fuel economy impacts are attributed only to PM control.

6.2.3.4 Operating Costs Associated CCV Maintenance on New Engines

For CCV systems, we have used a maintenance interval of 675 hours for all engines and a cost per maintenance event of $8 to $48 for small to large engines. The 675 maintenance interval is chosen as twice the oil change maintenance interval. CCV maintenance is assumed to be done during every other oil change event; this results in $0 labor cost for CCV maintenance. The calculation of operating costs associated with CCV maintenance are shown in Table 6.2-28. On a weighted basis, these costs are 0.2 cents per gallon and would be incurred only by new engines equipped with a CDPF.

Operating costs associated with CCV maintenance are attributed evenly to NOx and PM control.

Table 6.2-28
Closed Crankcase Ventilation System
Maintenance Costs for New Turbo-Charged Engines ($2001)

CCV Maintenance Costs	Units								
Rated Power	hp	0-25	25-50	50-75	75-175	175-300	300-600	600-750	750+
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.38996	0.367	0.367	0.367	0.367
Fuel Density	lbm/gallon	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Population Weighted Avg. Horsepower	hp	18	37	67	113	223	381	717	1263
Population Weighted Avg. Activity	hrs/year	524	579	707	696	525	585	931	921
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.44	0.47	0.56	0.56	0.55	0.54
CCV Filter Replacement Interval	hours	675	675	675	675	675	675	675	675
CCV Filter Replacement Cost	$/event	$8	$8	$8	$8	$10	$12	$24	$48
Filter Maintenance Labor	$/event	$0	$0	$0	$0	$0	$0	$0	$0
Total Filter Maintenance Cost per event	$/event	$8.00	$8.00	$8.00	$8.00	$9.60	$12.00	$24.00	$48.00
Fuel Use Between Maintenance Interval	gallons/period	286	631	1,143	1,969	4,357	7,444	13,759	23,796
Turbcharged Fleet Fraction	[%]	0%	5%	41%	41%	73%	100%	100%	100%
Maintenance Cost	$/gallon	$0.028	$0.013	$0.007	$0.004	$0.002	$0.002	$0.002	$0.002
Fuel Use Weightings	% total	0.0%	0.2%	5.7%	10.7%	16.9%	17.7%	4.1%	7.5%

6.3 Equipment-Related Costs

Costs of control to equipment manufacturers include fixed costs (those costs for equipment redesign and for tooling), and variable costs (for new hardware and increased equipment assembly time). According to the PSR Sales Database for the year 2000,[50] there are approximately 600 nonroad equipment manufacturers using diesel engines in several thousand different equipment models. We realize that the time needed for equipment manufacturers to make the necessary changes on such a large number of equipment models will vary significantly from manufacturer to manufacturer and from application to application. One of the goals of the proposed transition program for equipment manufacturers (TPEM) is to reduce the potential for anomalously high costs for individual equipment models by providing significant additional time (up to 7 years) for developing less costly designs or to align the changes with an already scheduled redesign. To present a conservative estimate of equipment-related costs, we have assumed that the industry does not use the TPEM program which, we believe, offers the opportunity for significant cost reductions. However, in Section 6.3.3 of this Draft RIA we present an analysis of the potential cost savings of the TPEM program.

6.3.1 Equipment Fixed Costs

6.3.1.1 Equipment Redesign Costs

The projected modifications to equipment resulting from the proposed standards relate to packaging of the exhaust emission control hardware expected to be added by engine manufacturers to their new engines (see Section 6.2 for cost estimates of new emission control hardware). As noted in Section 6.2, the additional emission control hardware is proportional in size to engine displacement by a 4:1 ratio (1.5x engine displacement for both the CDPF and the NOx adsorber, and 1x displacement for the DOC that is part of the NOx adsorber system). We expect that equipment manufacturers will have to redesign their equipment to accommodate this new volume of hardware. We expect that some redesigns would be major in scale, while others would be minor in scale. For example, in some cases, the redesign would simply be bolting the new devices onto the existing design, but in most cases we expect devices to be designed into the piece of equipment such that their presence would not be obvious to the casual observer. Additionally, a redesign to accommodate a DOC (1x engine displacement) should be less intensive than a redesign to accommodate a CDPF/NOx adsorber system. Lastly, for >75 horsepower engines where proposed NOx standards are phased-in, we assume that the redesign effort for those final NOx phase-in pieces of equipment (i.e., when the phase-in goes from 50 percent to 100 percent) would be less costly than the first redesign effort.

6.3.1.1.1 Schedule of Equipment Redesigns

The proposal contains a variety of emission compliance dates for the range of nonroad diesel engines; these dates are as shown in Table 6.3-1. For this analysis, because we are assuming no use of the TPEM program, we assume that the timing of equipment redesigns would correlate to the implementation of the proposed engine standards assuming no use of the engine ABT program. This results in a redesign schedule as shown in Table 6.3-1. We have noted what percentage of equipment models would be redesigned in years for which proposed engine standards would be implemented. The table also notes what percentage are major redesign efforts and what percentage are minor efforts. We also note what percentage of the redesign costs are allocated to PM and what percentage to NOx.

Table 6.3-1
Equipment Redesign Assumptions for Equipment Manufacturers

Horsepower	Engine Standard Dates	Pollutant Allocation	Percent of Equipment Models Undergoing Minor Redesign	Percent of Equipment Models Undergoing Major Redesign
0<hp<25	2008	100% PM	100%	
25<=hp<50	2008	100% PM	100%	
	2013	50% PM 50% NOx		100%
50<=hp<75	2008	100% PM	100%	
	2013	100% PM		100%
75<=hp<175	2012	50% PM 50% NOx		100%
	2014	100% NOx	50%	
175<=hp<=750	2011	50% PM 50% NOx		100%
	2014	100% NOx	50%	
>750hp	2011	50% PM 50% NOx		50%
	2014	50% PM 50% NOx		50%

Note that we have assumed that all equipment redesigns for the 75 to 750 horsepower range are major in the first year of proposed engine standards and minor in the last year. The costs associated with such minor redesign efforts are assumed to be half those associated with major redesign efforts. We have done this because we believe that equipment manufacturers would expend less effort to redesign those pieces equipment needing to add only the NOx adsorber (in those years where NOx phase-ins change from 50 percent to 100 percent) for three reasons: (1) these models would already have been redesigned for the CDPF system and would already incorporate the necessary electronic systems into their design; (2) equipment manufacturers would, presumably, have gained experience during the major redesign phase that should make the minor redesign phase more efficient; and, (3) manufacturers aware of the future requirement will be able to make provisions in the first redesign that account for future needs. Therefore, the second redesign effort should be less intensive. For engines over 750 horsepower, we have projected that 50 percent of the engines would be redesigned to incorporate a CDPF/NOx adsorber system in 2011 with the remaining 50 percent being modified in 2014. These projections are consistent with the phase-in of the proposed standards; both redesign efforts are assumed to be major since we assume that the NOx phase-in engines/equipment would be the same as the PM phase-in engines/equipment.

Our equipment redesign cost estimates were developed based on our meetings and conversations with engine and equipment manufacturers, specific redesign cost estimates provided by equipment manufacturers for the redesign of equipment to accommodate engines meeting the Tier 2 standards, and our engineering judgment as needed. The following section details our assessment of costs to equipment manufacturers.

6.3.1.1.2 Costs of Equipment Redesigns

While developing our equipment redesign cost estimates for the proposed Tier 4 standards, we met with a wide range of equipment manufacturers. This included equipment manufacturers with annual revenues less than $50 million and engineering staffs of less than 10 employees, equipment manufacturers with annual revenues on the order of $200 million and engineering staffs on the order of 50 employees, and equipment manufacturers with annual revenue well in excess of $1 billion with annual research and development budgets of more than $100 million and engineering staffs of more than 500 employees.

During these meetings and discussions, it became apparent to us that, in spite of the significant engine technology differences between Tier 2/3 and Tier 4, the impact on equipment design and the need for redesign are similar. That is, for Tier 2, many engines have added electronic fuel systems, turbocharging, and charge-air-cooling. In addition, many Tier 2 engines rely on retarded fuel injection to lower NOx emissions, which therefore increase heat rejection and require the equipment manufacturers to install larger radiators and fans. The process of equipment redesign for Tier 2 involved engineering work to accommodate these new components (e.g., charge-air-coolers, turbochargers, larger radiators and fans) and electronic fuel systems. In many respects, this is similar to what will be required for Tier 4, where those engines which don’t have electronic fuel systems will require them, and equipment manufacturers will now need to integrate aftertreatment systems (as compared to charge-air-coolers, turbochargers, larger radiators and fans).

A number of the companies we met with in the past year provided us with specific redesign cost information for the existing nonroad standards, and in some cases projections for equipment redesigns necessary to integrate aftertreatment (these data are confidential business information). In addition to the companies we met with in the past year, we also received redesign cost estimates from a number of equipment companies during the Tier2/3 rulemaking regarding their projected costs for the Tier 2 standards (these data are confidential business information). The information provided to EPA through these various channels showed that there is a very wide range of cost estimates and actual cost data for redesigning nonroad equipment for the Tier 2 standards. In general, what we learned was those very large companies tend to allocate significantly more resources to equipment redesign than the medium or small companies.

We have used all this information and data, and our engineering judgement, to develop the redesign cost estimates presented in Table 6.3-2. This table presents fixed cost per motive and non-motive equipment model (motive equipment is that with some form of propulsion system while non-motive equipment has none, e.g., air compressors, generator sets, hydraulic power units, irrigation sets, pumps and welders) for each horsepower group. In general, non-motive equipment has fewer design demands than does motive equipment – no operator line-of-sight demands, fewer serviceability constraints, and almost no impact (collision) concerns. As a result, we have estimated a lower redesign cost for non-motive equipment relative to motive equipment.

Table 6.3-2
Estimated Equipment Redesign Costs Per Model

Horsepower	Motive	Non-Motive
0<hp<25	$50,000	$50,000
25<=hp<50		
2008	$50,000	$50,000
2013	$187,500	$75,000
50<=hp<75	$350,000	$100,000
75<=hp<100	$350,000	$100,000
100<=hp<175	$500,000	$100,000
175<=hp<300	$500,000	$100,000
300<=hp<600	$750,000	$100,000
600<=hp<=750	$750,000	$100,000
>750hp	$750,000	$100,000

Using the PSR database we were able to determine the number of equipment models and the type of equipment model (motive versus non-motive). We distinguished motive from non-motive using our Nonroad Model definition of stationary applications. Non-motive applications include air compressors, generator sets, pumps, hydraulic power units, irrigation sets, and welders. All other applications are considered motive.

6.3.1.2 Costs Associated with Changes to Product Support Literature

Equipment manufacturers are also expected to modify product support literature (dealer training manuals, operator manuals, service manuals, etc.) due to the product changes resulting from the new emission standards. For each product line of motive applications, we estimated that the level of effort needed by equipment manufacturers to modify the support literature would be about 100 hours – 75 hours of junior engineering time, and 20 hours of senior engineering time, and 5 hours of clerical time – which would be about $10,000. We projected that the level of effort needed by equipment manufacturers to modify support literature for each non-motive application product line would be about 50 hours (distributed similarly), which is equivalent to about $5,000. Table 6.3-3 contains the total costs per power category for changes to support literature.

Table 6.3-3
Costs Associated with Changes to Product Support Literature ($1,000's)

Horsepower	Motive models	Motive Cost	Non-motive models	Non-motive cost	Total Cost
0<hp<25	561	$5,610	159	$795	$6,405
25<=hp<50	705	$7,050	169	$845	$7,895
50<=hp<75	496	$4,960	138	$690	$5,650
75<=hp<100	722	$7,220	146	$730	$7,950
100<=hp<175	1289	$12,890	223	$1,115	$14,005
175<=hp<300	1222	$12,220	227	$1,135	$13,355
300<=hp<600	677	$6,770	178	$890	$7,660
600<=hp<=750	127	$1,270	0	$0	$1,270
>750hp	117	$1,170	0	$0	$1,170

6.3.1.3 Total Equipment Fixed Costs

The annual equipment fixed costs for each horsepower category are shown in Table 6.3-4. As was done for engine fixed costs, we have attributed only a portion of the equipment fixed costs to sales within the United States. We have done this because we believe that these efforts would be needed to sell equipment not only in the US, but also in Australia, Canada, Japan, and the countries of the European Union. Therefore, as was discussed in more detail in section 6.2.1.1, we have attributed 42 percent of the equipment fixed costs to U.S. sales.

The analysis projected that the costs would be incurred over a two year period prior to the first year of the emission standards. The costs were then amortized over 10 years at a seven percent rate beginning with the first year of the engine standard to reflect the time value of money. The 10 year period for amortization, as opposed to the five year period used for engine costs, reflects the longer product development cycles for equipment relative to engines.

Per unit fixed costs are shown in Table 6.3-5 and use our projections of engine growth as presented in Table 8-1.

Table 6.3-4
Recovered (Annualized) Equipment Fixed Costs per Horsepower Category ($2001, in thousands of dollars)

Year	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<100	100<=hp<175	175<=hp<300	300<=hp<600	600<=hp<=750	>750hp	Total
2008	$1,541	$1,938	$1,372	$0	$0	$0	$0	$0	$0	$4,852
2009	$1,541	$1,938	$1,372	$0	$0	$0	$0	$0	$0	$4,852
2010	$1,541	$1,938	$1,372	$0	$0	$0	$0	$0	$0	$4,852
2011	$1,541	$1,938	$1,372	$0	$0	$19,941	$17,526	$3,246	$1,693	$47,257
2012	$1,541	$1,938	$1,372	$7,811	$19,662	$19,941	$17,526	$3,246	$1,693	$74,730
2013	$1,541	$7,261	$5,383	$7,811	$19,662	$19,941	$17,526	$3,246	$1,693	$84,064
2014	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2015	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2016	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2017	$1,541	$7,261	$5,383	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$102,804
2018	$0	$5,323	$4,011	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$97,952
2019	$0	$5,323	$4,011	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$97,952
2020	$0	$5,323	$4,011	$9,764	$24,578	$24,926	$21,907	$4,057	$3,387	$97,952
2021	$0	$5,323	$4,011	$9,764	$24,578	$4,985	$4,381	$811	$1,693	$55,547
2022	$0	$5,323	$4,011	$1,953	$4,916	$4,985	$4,381	$811	$1,693	$28,074
2023	$0	$0	$0	$1,953	$4,916	$4,985	$4,381	$811	$1,693	$18,740
Total	$15,413	$72,610	$53,832	$97,642	$245,775	$249,256	$219,073	$40,570	$33,867	$1,028,036

Table 6.3-5

Recovered Equipment Fixed Cost per Unit ($2001)

	0<hp<25		25<=hp<50		50<=hp<75		75<=hp<100	
Year	Sales	$/unit	Sales	$/unit	Sales	$/unit	Sales	$/unit
2008	152,087	$10	161,021	$12	110,279	$12	80,659	$0
2009	156,203	$10	164,526	$12	112,325	$12	82,158	$0
2010	160,319	$10	168,031	$12	114,371	$12	83,657	$0
2011	164,435	$9	171,536	$11	116,416	$12	85,157	$0
2012	168,551	$9	175,041	$11	118,462	$12	86,656	$90
2013	172,667	$9	178,546	$41	120,507	$45	88,155	$89
2014	176,783	$9	182,051	$40	122,553	$44	89,654	$109
2015	180,899	$9	185,556	$39	124,599	$43	91,154	$107
2016	185,015	$8	189,061	$38	126,644	$43	92,653	$105
2017	189,131	$8	192,566	$38	128,690	$42	94,152	$104
2018	193,247	$0	196,071	$27	130,736	$31	95,652	$102
2019	197,363	$0	199,576	$27	132,781	$30	97,151	$101
2020	201,479	$0	203,081	$26	134,827	$30	98,650	$99
2021	205,595	$0	206,586	$26	136,872	$29	100,149	$97
2022	209,711	$0	210,091	$25	138,918	$29	101,649	$19
2023	213,827	$0	213,596	$0	140,964	$0	103,148	$19

	100<=hp<175		175<=hp<300		300<=hp<600		600<=hp<=750		>750hp	
Year	Sales	$/unit	Sales	$/unit	Sales	$/unit	Sales	$/unit	Sales	$/unit
2008	130,909	$0	73,163	$0	37,583	$0	3,152	$0	3,193	$0
2009	133,230	$0	74,577	$0	38,019	$0	3,202	$0	3,244	$0
2010	135,551	$0	75,991	$0	38,455	$0	3,252	$0	3,295	$0
2011	137,872	$0	77,405	$258	38,891	$451	3,302	$983	3,346	$506
2012	140,193	$140	78,819	$253	39,327	$446	3,352	$968	3,397	$498
2013	142,514	$138	80,233	$249	39,763	$441	3,402	$954	3,448	$491
2014	144,836	$170	81,647	$305	40,199	$545	3,452	$1,175	3,499	$968
2015	147,157	$167	83,061	$300	40,635	$539	3,502	$1,158	3,550	$954
2016	149,478	$164	84,475	$295	41,071	$533	3,552	$1,142	3,601	$940
2017	151,799	$162	85,889	$290	41,507	$528	3,602	$1,126	3,652	$927
2018	154,120	$159	87,303	$286	41,943	$522	3,652	$1,111	3,703	$915
2019	156,441	$157	88,717	$281	42,379	$517	3,702	$1,096	3,754	$902
2020	158,762	$155	90,131	$277	42,815	$512	3,752	$1,081	3,805	$890
2021	161,083	$153	91,545	$54	43,251	$101	3,802	$213	3,856	$439
2022	163,404	$30	92,959	$54	43,687	$100	3,852	$211	3,907	$433
2023	165,725	$30	94,373	$53	44,123	$99	3,902	$208	3,958	$428

Costs per unit vary from year to year due to proposed standard phase-ins. The rapid decline in per unit costs during the final two or three years for >75 horsepower engines is because the latter redesign work – to accommodate the final year of the NOx phase-in – is considered a minor and less costly redesign, as was discussed above.

6.3.2 Equipment Variable Costs

In addition to the incrementally higher cost of new engines estimated in section 6.2.1 and 6.2.2, equipment manufacturers would need to purchase hardware to mount the new exhaust emission control devices within each newly redesigned piece of equipment. Note that the redesign costs we have already discussed are for changes in equipment design to accommodate aftertreatment devices. We assume that there are minimal changes to the variable costs for the redesigned elements of the equipment (i.e., the redesigned elements cost roughly the same as before) because they serve the same function and contain the same amount of materials. Here, we estimate the costs associated with the new hardware that will be necessary – new brackets, bolts, and sheet metal – for mounting and housing the new aftertreatment devices.

Here, we estimate the cost for additional sheet metal that could be used to shroud or otherwise encase aftertreatment system within the confines of the hood or other body cladding on a piece of equipment. The amount of metal for the shroud was determined using the engine displacement per equipment model information in the 2002 PSR Sales Database. The volume of the CDPF and NOx adsorber aftertreatment was calculated for each model in the PSR database which incorporated an engine over 75hp (1.5 times engine displacement for CDPF and the same for NOx adsorber). The DOC was assumed to fit in place of the muffler. The volume of the aftertreatment was then converted to the volume of a cube and two inches were added to each dimension for space between the aftertreatment and the shroud. Sheet metal was assumed to cover four sides of the aftertreatment with no cover for the bottom or equipment facing side of the shroud. Sheet metal was assumed to cost $1.10 per square foot for hot rolled steel. The cost for each model was multiplied by the total sales for that model using the 2000 sales information in the 2002 PSR Sales Database. The total costs were summed for each power group and then divided by the total sales for the power group for a sales weighted average cost. These costs were then added to variable cost estimates for brackets and bolts required to secure the aftertreatment devices within the equipment, other such miscellaneous items including weldments, plastics, castings, gaskets, seals, and hoses, as well as the labor required to install the new aftertreatment devices. A twenty-nine percent markup for overhead and profit is also included in the final cost estimate as shown in Table 6.3-6.

Table 6.3-6
Equipment Variable Costs[a]

Horsepower	Year	Bolts	Sheet Metal	Labor	Subtotal	29% Markup	Total
0<hp<25	2008	$0	$0	$0	$0	$0	$0
25<=hp<50	2013	$4	$0	$10	$14	$4	$18
50<=hp<75	2013	$4	$0	$10	$14	$4	$18
75<=hp<100	2012	$20	$3	$20	$42	$12	$55
100<=hp<175	2012	$20	$3	$20	$43	$12	$55
175<=hp<300	2011	$20	$5	$29	$54	$16	$70
300<=hp<600	2011	$40	$6	$59	$105	$30	$135
600<=hp<=750	2011	$40	$9	$59	$108	$31	$139
>750hp	2011	$80	$14	$78	$173	$50	$223

[a] Some equipment types have strict surface temperature requirements for exhaust components. Air gapping and water jacketing systems are on such engines and would likely be extended to include the area of the aftertreatment. Such costs are not included in this analysis for these costs would only apply to specialized equipment (<1%). However, costs have been calculated in a memo to the docket (docket A-2001-28).

As shown in Table 6.3-6, we have estimated equipment variable costs for less than 25 horsepower equipment to be $0 under the assumption that an added DOC would replace the existing muffler and make use of the same bracket/bolt/labor used for the muffler. This is also assumed for engines in the 25 to 75 horsepower range during the years 2008 through 2012 when only a DOC is being used by the engine manufacturer for compliance; additional bolts and labor costs are added for the addition of a CDPF beginning in 2013.[H] While we have assumed the CDPF will simply replace the muffler, there will be additional bracket/bolt/labor demands due to the greater weight of the CDPF relative to the replaced muffler.

6.3.3 Potential Impact of the Transition Provisions for Equipment Manufacturers

As discussed in Section VII.B of the preamble, we have proposed to extend the Transition Provisions for Equipment Manufacturers (TPEM) which were developed in the 1998 nonroad rule into the proposed Tier 4 program (with a number of modifications as discussed in Section VII.B of the preamble). The TPEM is an important component of our proposal because of the flexibility it provides for equipment manufacturers. However, as explained earlier, because the program is optional, we have not included an estimate of the potential impacts of the program on the overall costs of our proposed Tier 4 program. Nevertheless, in this section we discuss why the TPEM program can have a substantial impact reducing equipment manufacturer costs.

[H] Note that, for costing purposes, we have assumed that a DOC is used on all <75 horsepower engines to comply with the 2008 standards although test data suggests that some engines may not need to add a DOC because they would already meet the proposed standards.

The TPEM can reduce equipment manufacturer costs in two ways. First, the proposed Tier 4 TPEM program would allow equipment manufacturers to continue to sell a limited number of equipment with non-Tier 4 engines even after the Tier 4 standards go into effect. Therefore, any engine price increase associated with the proposed Tier 4 standards would not be incurred by the equipment manufacturer or by the end user during the time frame the manufacturers make us of the TPEM. Second, the TPEM program allows manufacturers to schedule equipment design cycles so that the normal redesign cycle can overlap with any redesign necessary because of EPA's emission standards. We believe this is the most significant cost savings impact of the TPEM. This is due to the fact that many equipment manufacturers have a number of small volume equipment model lines. Using the TPEM program, companies can delay the redesign costs associated with Tier 4 engines for up to seven years on a limited number of products.

We performed a detailed analysis on an equipment manufacturer-by-equipment manufacturer basis of the more than 6,000 equipment models and 600 equipment manufacturers contained in an industry-wide database (the Power Systems Research database).[51] This analysis looked at each equipment manufacturers product offerings (e.g., different equipment models) by power category and the estimated 2000 U.S. sales of each equipment model. We used this database to analyze how equipment manufacturers could make use of the proposed TPEM program to maximize the number of equipment models which could take advantage of the TPEM to delay any equipment redesign associated with the proposed Tier 4 standards until the eighth year of the program (as discussed in Section VII.B of the preamble, we have proposed to allow the TPEM program to last until seven years after the Tier 4 standards are implemented.). We specifically analyzed the proposed 80 percent allowance and the small volume option we have requested comment on (as discussed in the preamble). The results are shown in Table 6.3-7.

Table 6.3-7
Potential Impact of TPEM Program on Equipment Models and Sales

Equipment Models/ Equipment Sales	Engine Power Category					
	<25 hp	25< hp <70[a]	70[a]< hp <175	175< hp <750	>750 hp	All Power Categories
% of all equipment **models** which could use TPEM for full-seven years	56%	61%	66%	71%	80%	66%
Percent of equipment **sales** which could use TPEM for full-seven years	7%	10%	13%	12%	21%	10%

a Note, the proposed power ranges are 25-75 and 75-175 hp. This analysis was done using 70 hp as a cut-point. We do not believe the results of this analysis would have been significantly different if the power outpoint was reduce at 75hp.

This analysis indicates that if fully utilized by equipment manufacturers, 66 percent of all of the nonroad diesel equipment models could use the TPEM program to delay an equipment redesign necessary for the Tier 4 standards for seven years. Without the TPEM program, equipment manufactures would need to redesign all of their equipment models which used a nonroad diesel engine in the first year of the engine standard implementation. As an example of the flexibility offered by the TPEM program, Table 6.3-7 indicates that for the 25 - 75 hp category, 61 percent of all equipment models in this power range could take advantage of the TPEM to delay an equipment redesign for seven years. It is important to note that while the

TPEM can substantially reduce equipment redesign costs, it would be expected to have a much smaller impact on the emission reductions of the program. While the TPEM can allow equipment companies to continue selling products with the previous tier standards on many equipment models, the total sales which can be impacted by the TPEM (also shown in Table 6.3-7) is estimated to be no higher than ten percent for no more than seven years.

6.4 Summary of Engine and Equipment Costs

Details of our engine and equipment cost estimates were presented in Sections 6.2 and 6.3. Here we summarize the cost estimates.

6.4.1 Engine Costs

6.4.1.1 Engine Fixed Costs

Engine fixed costs include costs for engine R&D, tooling, and certification. These costs were discussed in detail in Section 6.2.1. The total estimated engine fixed costs are summarized in Table 6.4-1.

Table 6.4-1
Summary of Engine Fixed Costs (millions)

	Incurred Costs	Recovered Costs
R&D	$199	$279
Tooling	$67	$81
Certification	$72	$88
Total	$338	$448

6.4.1.2 Engine Variable Costs

Engine variable costs were discussed in detail in Section 6.2.2. For engine variable costs, we have generated cost estimation equations as a function of engine displacement or number of cylinders. These equations are summarized in Table 6.4-2. Note that not all equations were used for all engines; equations were used in the manner shown in Table 6.4-2. We have calculated the aggregate engine variable costs and present them in Chapter 8 of this Draft RIA. The net present value of these variable costs between the years 2004 through 2036 is $13.9 billion.

Table 6.4-2
Summary of Cost Equations for
Engine Variable Costs (x represents the dependent variable)

Engine Technology	Time Frame[a]	Cost Equation	Dependent Variable (x)	How Used
NOx Adsorber System	Near term Long term	\$105(x) + \$180 \$84(x) + \$158	Displacement[b]	>75hp engines according to phase-in of NRT4 NOx std.
CDPF System	Near term Long term	\$150(x) + \$71 \$114(x) + \$54	Displacement	>25hp engines according to NRT4 PM std.
CDPF Regen System – IDI engines	Near term Long term	\$20(x) + \$289 \$15(x) + \$219	Displacement	IDI engines adding a CDPF
CDPF Regen System – DI engines	Near term Long term	\$10(x) + \$144 \$7(x) + \$110	Displacement	DI engines adding a CDPF
DOC	Near term Long term	\$19(x) + \$117 \$18(x) + \$110	Displacement	<25hp engines beginning in 2008; 25-75hp engines 2008 thru 2012
CCV System	Near term Long term	\$2(x) + \$35 \$2(x) + \$25	Displacement	All turbo-charged engines when they first meet a proposed PM std.
Cooled EGR System	Near term Long term	\$17(x) + \$69 \$13(x) + \$51	Displacement	25-50 hp engines beginning in 2013
Common Rail Fuel Injection (mechanical fuel system baseline)	Near term Long term	\$77(x) + \$627 \$57(x) + \$477	# of cylinders/ injectors	25-50 hp DI engines when they add a CDPF
Common Rail Fuel Injection (electronic rotary fuel system baseline)	Near term Long term	\$66(x) + \$175 \$49(x) + \$132	# of cylinders/ injectors	50-75 hp DI engines when they add a CDPF

[a] Near term = years 1 & 2; Long term = years 3+. Explanation of near term and long term can be found in Section 6.1.

[b] Displacement refers to engine displacement in liters.

6.4.1.3 Engine Operating Costs

Engine operating costs are discussed in detail in Section 6.2.3. Table 6.4-3 summarizes engine operating costs, excluding costs associated with the desulfurization of diesel fuel; these costs are presented in Chapter 7 of this Draft RIA.

Table 6.4-3
Engine Operating Costs Associated with the Proposed Fuel Program
(cents/gallon of fuel consumed)

Horsepower category	Oil Change Savings	CDPF Maintenance	CCV Maintenance	CDPF Regeneration[a]	Net Operating Costs[b]
0<hp<25	(17.5)	0.0	0.0	0.0	(17.5)
25≤hp<50	(8.3)	2.3	1.3	1.30	(3.4)
50≤hp<75	(5.0)	1.3	0.7	1.30	(1.7)
75≤hp<175	(3.2)	0.7	0.4	0.65	(1.5)
175≤hp<300	(2.1)	0.2	0.2	0.65	(1.1)
300≤hp<600	(1.5)	0.1	0.2	0.65	(0.6)
600≤hp<750	(1.1)	0.1	0.2	0.65	(0.2)
>750hp	(1.2)	0.2	0.2	0.65	(0.2)
Locomotive/Marine	(1.1)	0.0	0.0	0.0	(1.1)

[a] A one or two percent fuel consumption increase, a 60 cent/gallon baseline fuel price, and a 4.8 cent/gallon incremental fuel cost.
[b] The incremental costs for the proposed low sulfur fuel are not included here. Fuel costs are presented in Chapter 7 of this Draft RIA.

Engines that make up the existing fleet would realize the oil change savings shown in Table 6.4-3 while incurring none of the other operating costs because these engines would not be equipped with a CDPF system or be adding a CCV system. New engines would incur all the costs and savings shown in Table 6.4-3.

Table 6.4-3 shows operating costs on a cent per gallon basis. Lifetime engine operating costs vary by the amount of fuel consumed. We have calculated lifetime operating costs for some example pieces of equipment and present those in Section 6.5. Aggregate operating costs – the annual total costs – are presented in Chapter 8 of this Draft RIA.

6.4.2 Equipment Costs

6.4.2.1 Equipment Fixed Costs

Equipment fixed costs were discussed in detail in Section 6.3.1. Table 6.4-4 shows estimated equipment fixed costs associated with the proposed program. These costs include costs for equipment redesign and generation of new product support literature.

Table 6.4-4
Summary of Equipment Fixed Costs (millions)

	Incurred Costs	Recovered Costs
Redesign	$678	$999
Product Literature	$19	$29
Total	$697	$1,028

6.4.2.2 Equipment Variable Costs

Equipment variable costs are discussed in detail in Section 6.3.2. Table 6.4-5 shows our estimated per unit equipment variable costs. This table is a repeat of Table 6.3-6.

Table 6.4-5
Equipment Variable Costs per Unit

Horsepower	Year	Bolts	Sheet Metal	Labor	Subtotal	29% Markup	Total
0<hp<25	2008	$0	$0	$0	$0	$0	$0
25<=hp<50	2013	$4	$0	$10	$14	$4	$18
50<=hp<75	2013	$4	$0	$10	$14	$4	$18
75<=hp<100	2012	$20	$3	$20	$42	$12	$55
100<=hp<175	2012	$20	$3	$20	$43	$12	$55
175<=hp<300	2011	$20	$5	$29	$54	$16	$70
300<=hp<600	2011	$40	$6	$59	$105	$30	$135
600<=hp<=750	2011	$40	$9	$59	$108	$31	$139
>750hp	2011	$80	$14	$78	$173	$50	$223

We have calculated the aggregate equipment variable costs in Chapter 8 of this Draft RIA. Those costs show the annual total variable costs we have estimated for our proposal. The net present value of these variable costs between the years 2004 through 2036 is $498 million.

6.5 Costs for Example Pieces of Equipment

6.5.1 Summary of Costs for Some Example Pieces of Equipment

To better illustrate the engine and equipment cost impacts we are estimating for today's proposed standards, we have chosen several example pieces of equipment and presented the estimated costs for them. Using these examples, we can calculate the costs for a specific piece of equipment in several horsepower ranges and better illustrate the cost impacts of today's proposed standards. These costs along with information about each example piece of equipment are shown in Table 6.5-1. Costs presented are near term and long term costs for the final standards to which each piece of equipment would comply. Long term costs are only variable costs and, therefore, represent costs after all fixed costs have been recovered. Included in the table are estimated prices for each piece of equipment to provide some perspective on how our estimated control costs relate to existing equipment prices.

Table 6.5-1
Near Term and Long Term Costs for Several Example Pieces of Equipment[a]
($2001, for the final emission standards to which the equipment must comply)

	GenSet	Skid/Steer Loader	Backhoe	Dozer	Ag Tractor	Dozer	Off-Highway Truck
Horsepower	9 hp	33 hp	76 hp	175 hp	250 hp	503 hp	1000 hp
Displacement (L)	0.4	1.5	3.9	10.5	7.6	18	28
# of cylinders/injectors	1	3	4	6	6	8	12
Aspiration	natural	natural	turbo	turbo	turbo	turbo	turbo
Fuel System	DI	DI	DI	DI	DI	DI	DI
Incremental Engine & Equipment Cost							
Long Term	$120	$760	$1,210	$2,590	$2,000	$4,210	$6,780
Near Term	$170	$1,100	$1,680	$3,710	$2,950	$6,120	$10,100
Estimated Equipment Price[b]	$3,500	$13,500	$50,000	$235,000	$130,000	$575,000	$700,000
Incremental Operating Costs[c]	-$90	$40	$370	$1,550	$1,320	$4,950	$12,550
Baseline Operating Costs (Fuel & Oil only)[c]	$940	$2,680	$7,960	$77,850	$23,750	$77,850	$179,530

a. Near-term costs include both variable costs and fixed costs; long-term costs include only variable costs and represent those costs that remain following recovery of all fixed costs.
b. "Estimated Price of New Nonroad Example Equipment," memorandum from Zuimdie Guerra to docket A-2001-28.[52]
c. Present value of lifetime costs.

6.5.2 Method of Generating Costs for Our Example Pieces of Equipment

To facilitate the readers ability to duplicate this example analysis for other pieces of equipment, this section will briefly describe the necessary steps to create the cost analysis based on the information contained in this Draft RIA.

The first step required to develop an estimate of our projected cost for control under the proposed Tier 4 program is to define certain characteristics of the engine in the piece of equipment for which a cost estimate is desired. Specifically, the following items must be defined:

- displacement of the engine (i.e., the cylinder swept volume) in liters;
- type of aspiration (i.e., turbocharged or naturally aspirated);
- number of cylinders;
- type combustion system used by the engine (i.e., indirect-injection, IDI, or direct injection, DI);
- model year of production; and,
- the horsepower category of the engine.

With this information, and the data tables contained in this Draft RIA, an estimate of the compliance costs can be made.

As an example, here we will estimate the cost of compliance for the 76hp backhoe in the year 2012. Table 6.5-1 shows the near term cost to be $1,680 and the long term cost to be $1,210. The first step is to define our engine characteristics as shown in Table 6.5-2.

Table 6.5-2
Engine and Equipment Characteristics of an Example Cost Estimate

76 hp Backhoe Example		
Model Year	2012	reader defined
Displacement (liters)	3.9	application specific
Cylinder (number)	4	application specific
Aspiration	Turbocharged	application specific
Combustion System	Direct Injection	application specific
Horsepower Category	75 to 175 hp	regulations define the standards and the timing of the standards

For engines produced in the early years of the program, an accounting of the fixed costs needs to be made. Fixed costs include the engine fixed cost for research and development, tooling, and certification as well as equipment fixed includes including redesign and manual costs. These fixed costs are reported in this chapter on a per engine/piece of equipment basis in each year of the program for which a fixed cost is applied. The necessary numbers to calculate the fixed costs can simply be read from these tables.

Table 6.5-3
Fixed Costs for an Example Cost Estimate

2012 76hp Backhoe Example		
Engine R&D	$27	Table 6.2-4 Engine R&D Costs (per engine)
Engine Tooling	$15	Table 6.2-6 Engine Tooling Costs (per engine)
Engine Certification	$11	Table 6.2-8 Engine Certification Costs (per engine)
Equipment Fixed	$90	Table 6.3-5 Equipment Fixed Cost per Unit
Total Fixed Costs	$143	Summation

The engine variable costs are related to specific engine technology characteristics in a series of linear equations described in table 6.4-2. The table includes all of the different variable cost components for different size ranges of engines meeting different proposed standards. It includes a description of the particular engine categories for which the costs are incurred. The simplest approach to estimating the variable costs is to repeat the table and then to simply zero out any components which do not apply for a particular example (see Table 6.5-4 below).

Table 6.5-4
Summary of Cost Equations for Engine Variable Costs for a 76hp Backhoe Example (x represents the dependent variable)

Engine Technology	Time Frame[a]	Cost Equation	Dependent Variable (x)	How Used
NOx Adsorber System	Near term Long term	\$105(x) + \$180 \$84(x) + \$158	Displacement[b]	>75hp engines according to phase-in of NRT4 NOx std.
2012 76hp Backhoe	2012 is Near Term	\$105 (3.9)+\$180 = \$590	3.9 liters	In 2012 a 76 hp engine in the NOx phase-in set would require a NOx adsorber
CDPF System	Near term Long term	\$150(x) + \$71 \$114(x) + \$54	Displacement	>25hp engines according to NRT4 PM std.
2012 76hp Backhoe	2012 is Near Term	\$150(3.9)+\$71= \$656	3.9 liters	In 2012 all 76hp engines are projected to require CDPFs
CDPF Regen System – IDI engines	Near term Long term	\$20(x) + \$289 \$15(x) + \$219	Displacement	IDI engines adding a CDPF
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	The example engine has a direct injection (DI) combustion system not an indirect injection (IDI)
CDPF Regen System – DI engines	Near term Long term	\$10(x) + \$144 \$7(x) + \$110	Displacement	DI engines adding a CDPF
2012 76hp Backhoe	2012 is Near Term	\$10(3.9)+\$144= \$183	3.9 liters	The example engine is a DI engine and has a CDPF
DOC	Near term Long term	\$19(x) + \$117 \$18(x) + \$110	Displacement	<25hp engines beginning in 2008; 25-75hp engines 2008 thru 2012
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example engine rated power is greater than 75 hp
CCV System	Near term Long term	\$2(x) + \$35 \$2(x) + \$25	Displacement	All turbo-charged engines when they first meet a proposed PM std.
2012 76hp Backhoe	2012 is Near Term	\$2(3.9)+\$35= \$43	3.9 liters	The example engine is turbocharged
Cooled EGR System	Near term Long term	\$17(x) + \$69 \$13(x) + \$51	Displacement	25-50 hp engines beginning in 2013
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example rated power is greater than 50 hp
Common Rail Fuel Injection (mechanical fuel system baseline)	Near term Long term	\$77(x) + \$627 \$57(x) + \$477	# of cylinders/ injectors	25-50 hp DI engines when they add a CDPF
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example rated power is greater than 50 hp
Common Rail Fuel Injection (electronic rotary fuel system baseline)	Near term Long term	\$66(x) + \$175 \$49(x) + \$132	# of cylinders/ injectors	50-75 hp DI engines when they add a CDPF
2012 76hp Backhoe	2012 is Near Term	not applicable	3.9 liters	Example rated power is greater than 75 hp

[a] Near term = years 1 & 2; Long term = years 3+. Explanation of near term and long term can be found in Section 6.1.

[b] Displacement refers to engine displacement in liters.

Summing the applicable variable costs estimated in table 6.5-4 gives a total engine variable cost for the 76hp Backhoe example of $1472. The equipment variable costs are presented in table 6.4-3 and are referenced by engine power category. For the 76hp example here, the estimated equipment variable costs are $55.

Having estimated the engine and equipment fixed and variable costs it is possible to estimate the total new product costs (excluding operating costs changes) by simply totaling the fixed and variable costs estimate here. The resulting total is $1670 ($143 + $1472 + $55, note that rounding may result in slightly different results). Typically we have presented these total cost estimates to the nearest ten dollars.

Chapter 6 References

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