CHAPTER 6: Estimated Engine and Equipment Costs

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This chapter presents the engine and equipment costs we have estimated for meeting the new engine emissions standards. Section 6.1 includes a brief outline of the methodology used to estimate the engine and equipment costs. Sections 6.2 and 6.3 present the projected costs of the individual technologies we expect manufacturers to use to comply with the new emissions standards, along with a discussion of fixed costs such as research and development (R&D), tooling, certification, and equipment redesign. Section 6.4 summarizes these costs and Section 6.5 details cost estimates for several example pieces of equipment. A complete presentation of the aggregate cost of compliance for engines and equipment is in Chapter 8.

Note that the costs presented here are for those nonroad engines and equipment that are mobile nonroad equipment and are, therefore, subject to nonroad engine standards. These costs would not apply for that equipment that is stationary—some portion of some equipment segments such as generator sets, pumps, compressors—and not subject to nonroad engine standards. The reader should know that some nonroad diesel equipment is not covered by nonroad engine standards. Those nonroad engines that receive permits from local authorities as stationary source emitters (i.e., some gensets, pumps, compressors, etc.) are not covered by nonroad engine standards. In most cases, for what are very similar products, some fraction will be permitted as stationary sources while others remain mobile sources.

To maintain consistency in the way our emission reductions, costs, and cost-effectiveness estimates are calculated, our cost methodology for engines and equipment relies on the same projections of new nonroad engine growth as those used in our emissions inventory projections. Our NONROAD emission inventory model includes estimates of future engine populations that are consistent with the future engine sales used in our cost estimates. The NONROAD model inputs include an estimate of what percentage of gensets sold in the U.S. are "mobile" and, thus, subject to the nonroad standards, and what percentage are "stationary" and not subject to the nonroad standards. These percentages vary by power category and are documented in "Nonroad Engine Population Estimates," EPA Report 420-P-02-004, December 2002. For gensets >750 horsepower, NONROAD assumes 100 percent are stationary and, therefore, not subject to the new nonroad standards. For gensets <750 horsepower, we have assumed other percentages of mobile versus stationary. During our discussions with engine manufacturers after the proposal, it became apparent not only that our estimate for >750 horsepower gensets may not be correct and many are indeed mobile, but also that some of our estimates for <750 horsepower gensets may also not be correct and many more than we estimate may indeed be mobile. If true, this increased percentage of mobile gensets will be subject to the new nonroad standards. Unfortunately, we have not received sufficient data to make a conclusive change to the NONROAD model and, therefore, for the above described purpose of maintaining consistency, we have not included the costs or the emissions reductions in our official estimates for this final rule. In Chapter 8, Appendix A, we present a sensitivity analysis that includes both an estimate of the costs and emissions reductions that would result from including a higher percentage of gensets as mobile machines and subject to the new standards.

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. In addition, we have assumed that engine companies who are eligible for the small business engine manufacturer specific provisions *do not* take advantage of the unique flexibilities the rule provides for them, which includes the opportunity to delay compliance with the Tier 4 emission standards for a full three model years. While we fully expect companies to use them to reduce compliance costs, we do not factor them into the cost analysis because they are voluntary programs. This analysis of compliance costs relates to regulatory requirements that are part of the nonroad Tier 4 final rule. Unless noted otherwise, all costs are in 2002 dollars.

6.1 Methodology for Estimating Engine and Equipment Costs

This analysis makes several simplifying assumptions regarding how manufacturers will comply with the new emission standards. First, in each power category, we assume a single technology recipe, as discussed in Chapter 4. However, we expect that each manufacturer will evaluate all possible technology avenues to determine how to best balance costs while ensuring compliance. As noted, for developing cost estimates, we have assumed that the industry does not use either the transition program for equipment manufacturers or averaging, banking, and trading, both of which offer the opportunity for significant cost reductions. Given these simplifying assumptions, we believe the projections presented here probably overestimate the costs of the different approaches toward compliance that manufacturers may ultimately take.

For smaller nonroad engines—those under 75 hp—many of the anticipated emission-control technologies will be applied for the first time. Therefore, we have sought input from a large section of the regulated community regarding the future costs of applying these technologies to diesel engines. Under contract with 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 manufacturers will use. These costs form the basis for our estimated costs for "traditional" engine technologies such as EGR and fuel-injection systems.[1] Note that, while these technologies are expected to be added to <75hp engines for the first time, they are being added, or will be, to >75hp engines to meet the Tier2/3 standards. We have used the same methodology to develop the costs for these technologies for <75hp engines as was used to develop the costs for >75hp engines.[2]

Costs for exhaust emission-control devices (for example, catalyzed diesel particulate filters (CDPF), NOx adsorbers, and diesel oxidation catalysts (DOC)) were estimated using the methodology used in our HD2007 rulemaking. In that rulemaking effort, ICF Consulting, under contract to EPA, provided surveys to nine engine manufacturers seeking information relevant to estimating the costs for and types of emission-control technologies that might be enabled with low-sulfur diesel fuel. The survey responses were used as the first step in estimating the costs for advanced emission-control technologies anticipated for meeting the HD2007 standards.[3] We then built upon these costs based on input from members of the Manufacturers of Emission Controls Association. Because the anticipated emission-control technologies 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 have used that analysis as the basis for estimating the costs of these technologies in this rulemaking.

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 on a direct cost to manufacture the system components plus a 29 percent markup to account for the supplier's overhead and profit or, when available, based on estimates from suppliers on expected total costs to the manufacturers (inclusive of markups).[4] Estimated variable costs for new technologies include a markup to account for increased warranty costs. Variable costs are additionally marked up to account for both manufacturer and dealer overhead and carrying costs. The manufacturer’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 estimated to be three percent of their direct costs to account for the cost of capital tied up in inventory. We adopted this same approach to markups in the HD2007 rule, based on industry input.[5]

We have also identified various factors that 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.[6] This analysis incorporates the effects of this learning curve as described in Section 6.2.2.

Fixed costs for engine R&D are estimated to be incurred over the five-year period preceding introduction of the engine.[A] Fixed costs for tooling and certification are estimated to be incurred one year ahead of initial production. Fixed costs for equipment redesign[B] 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 cost expenditures are amortized using a seven percent capital cost to reflect the time value of money. Engine fixed costs are then “recovered” over a five-year amortization period including the same seven percent cost of capital. This is true 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

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[A] There is one exception to this – for engine R&D conducted to support the new standards for <75 horsepower engines in the 2008 model year, we have used a four year period (i.e., 2004 through 2007) over which to spread the R&D expenditures.

[B] Throughout this analysis we use the term “redesign” to refer to all work needed to complete the equipment modifications we believe will be necessary to accommodate the engine changes that will result from the new engine standards.

during the five years following 100 percent compliance.[C] Equipment fixed costs are recovered over a 10-year amortization period including the same seven percent captial cost; 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, expected 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 simplified overview of the methodology used to estimate engine and equipment costs is 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 recovered costs represent our estimate of fixed costs associated with this final rule. 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 power categories in this cost analysis and by other factors (for example, the engine prices we have estimated) as discussed in more detail below. Because we do not know how manufacturers 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.

- For engine variable costs (i.e., emission-control hardware), we first estimate the cost per piece of technology/hardware. As described in detail in Section 6.2.2, emission-control hardware costs tend to be directly related to engine characteristics—for example, emission-control devices are sized according to engine displacement so costs vary by displacement; fuel-injection systems vary in cost according to how many fuel injectors are required so costs vary by number of cylinders. This way we are able to determine a variable cost equation as a function of engine displacement or as a function of the number of cylinders. We then consider each unique engine's baseline technology package using a database from Power Systems Research of all nonroad equipment sold in the United States.[7] That database lists engine characteristics for every one of over 4,500 unique equipment models sold in the United States and provides the sales of each piece of equipment. Using the baseline engine characteristics of each engine, the projected technology package for that engine, and the

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[C] We have estimated a "recovered" cost for all engine and equipment fixed costs to provide for a per-unit analysis of the cost of the final rule. In general, in environmental economics, it is more conventional to simply count the total costs of the program (i.e., opportunity costs) in the year they occur. However, this approach does not directly estimate a per-unit production cost since fixed costs occur before the standards take effect and, therefore, prior to the production of new compliant engines. In our methodology, fixed costs grow at a seven percent rate 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 capital cost to reflect the time value of money. Our intent is to reflect the cost of capital investments made in emissions control rather than investments made in other activities.

variable cost equations described in Section 6.2, we calculate a variable cost for the engine in each of the over 4,500 unique equipment models sold in the United States. This variable cost per engine is then multiplied by that engine's projected sales in each year for the years after the new standards take effect. 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.

- Note that the cost-per-ton calculation (see Chapter 8 of this RIA for our cost-per-ton analysis) is never impacted by how many power categories we use in our cost analysis. We sometimes break up the fleet into more power categories than would seem reasonable given the structure of the emission standards. We do this for several reasons: (1) phase-ins of standards and/or different levels of baseline versus new standards sometimes force such breakouts; and, (2) greater stratification (i.e., breaking up the 75 to 175 hp range and the 175 to 750 hp range) provides a better picture for use in our estimate of potential recovery of fixed costs. Importantly, the number of power categories used does not impact the total costs estimated as a result of the new emission standards, and these are the total 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 decrease as a result of several factors, as described below. All costs are presented in 2002 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 represent those technologies we believe will be used to comply with the Tier 4 emission standards. These technologies are also part of an ongoing research and development effort geared toward compliance with the HD2007 standards and, to some extent, the current and future light-duty diesel vehicle standards in the US and in Europe. Those engine manufacturers making R&D expenditures toward compliance with highway emission standards will have to undertake 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, while continuing to design engines with good performance, durability, and fuel efficiency characteristics. However, many nonroad engine manufacturers are not part of the ongoing R&D effort toward compliance with highway emission 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 expect the R&D expenditures for these nonroad-only manufacturers to be higher than for those manufacturers already conducting R&D in response to the HD2007 rule and the light-duty diesel requirements in the US and Europe.

We are projecting that several technologies will be used to comply with the Tier 4 emission standards. We are projecting that NOx adsorbers and CDPFs will be the most likely technologies used to meet the new emission standards for engines over 75 hp and, for engines between 25 and 75 hp, that CDPFs will be used in 2013 to meet the new PM standard. The fact that these technologies are being developed for implementation in the highway market before the emission standards in this final rule take effect, and the fact that engine manufacturers have several years to comply with the Tier 4 standards, ensures that the technologies used to comply with the nonroad standards will undergo significant development before reaching production. This ongoing development will likely lead to reduced costs in three ways. First, we expect research will lead to enhanced effectiveness for individual technologies, allowing manufacturers to use simpler packages of emission-control technologies than we would predict currently, given the current state of development. Second, we anticipate that the continuing effort to improve the emission-control technologies will include innovations that allow lower-cost production. And finally, we believe manufacturers will focus research efforts on any drawbacks, such as fuel economy impacts or maintenance costs, in an effort to minimize or overcome any potential negative effects.

We anticipate that manufacturers will introduce a combination of primary technology upgrades to meet the new emission standards. Achieving very low NOx emissions requires basic research on NOx emission-control technologies and improvements in engine management. Manufacturers are expected to address the challenge by optimizing the engine and exhaust emission-control system to realize the best overall performance. This will entail optimizing the engine and emission control system for both emissions and fuel economy performance in light of the presence of the new exhaust emission control devices and their ability to control pollutants previously controlled only via in-cylinder means or with exhaust gas recirculation. The 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 where we project use of both a CDPF and a NOx adsorber (i.e., 75 to 750 hp), we have attributed two-thirds of the R&D expenditures to NOx control, and one-third to PM control.[D]

[D] In order to avoid inconsistencies in the way our emission reductions, and cost-effectiveness estimates are calculated, our cost methodology for engines and equipment relies on the same projections of new nonroad engine growth as those used in our emissions inventory projections. Our NONROAD emission inventory model includes estimates of future engine populations that are consistent with the future engine sales used in our cost estimates. The NONROAD model inputs include an estimate of what percentage of gensets sold in the U.S. are "mobile" and, thus, subject to the nonroad standards, and what percentage are "stationary" and not subject to the nonroad standards. These percentages vary by power category and are documented in "Nonroad Engine Population Estimates," EPA

For this analysis, we have estimated two elements to engine R&D: (1) corporate R&D, or that R&D conducted by manufacturers using test engines to learn how NOx and PM control technologies work and how they work together in a system; and, (2) engine line specific R&D, or that R&D done to tailor the corporate R&D knowledge to each particular engine line. To distinguish between these two R&D elements, here we refer to the former as corporate R&D and the latter as engine line R&D.

With respect to the former of these R&D elements—corporate R&D—we begin with our HD2007 rule. In that rule, we estimated that each engine manufacturer would expend $35 million for R&D toward successfully implementing catalyzed diesel particulate filters (CDPF) and NOx adsorbers. For this analysis, we express all monetary values in 2002 dollars which means our HD2007 starting point equates to $36.1 million. For their nonroad R&D efforts on >75 hp engines – those engines where we project that compliance will require a CDPF and a NOx adsorber or CDPFs-only (engines >750 hp) – engine manufacturers that also sell into the highway market will 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, power and torque characteristics are often different, so manufacturers will need to expend some effort to accommodate those differences. For these manufacturers, we have estimated that they will incur an average R&D expense of $3.6 million not including the engine line R&D. This $3.6 million R&D expense allows for the transfer of learning from highway R&D to their nonroad engines. For reasons noted above, two-thirds of this R&D is attributed to NOx control and one-third to PM control for 75 to 750 hp engines; for the portion of this R&D that is allocated to engines >750 hp, all of this R&D is attributed to PM control.

For those manufacturers that sell larger engines only into the nonroad market, and where we project those engines to add a CDPF and a NOx adsorber (75 to 750 hp) or a CDPF-only (>750 hp), we believe they will incur a corporate R&D expense approaching that incurred by highway manufacturers for the highway rule although not quite at the same level[E]. Nonroad

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Report 420-P-02-004, December 2002. For gensets >750 horsepower, NONROAD assumes 100 percent are stationary and, therefore, not subject to the new nonroad standards. For gensets <750 horsepower, we have assumed other percentages of mobile versus stationary. During our discussions with engine manufacturers after the proposal, it became apparent not only that our estimate for >750 horsepower gensets may not be correct and many are indeed mobile, but also that some of our estimates for <750 horsepower gensets may also not be correct and many more than we estimate may indeed be mobile. If true, this increased percentage of mobile gensets will be subject to the new nonroad standards. Unfortunately, we have not received sufficient data to make a conclusive change to the NONROAD model to include the potentially increased percentages of mobile gensets and, therefore, for the above described purpose of maintaining consistency, we have not included their costs or their emissions reductions in our official estimates for this final rule (costs and emissions reductions for the current percentages in the NONROAD model are included in our estimates for the final rule). Instead, we present a sensitivity analysis in Chapter 8 of the RIA that includes both an estimate of the costs and emissions reductions that would result from including a higher percentage of gensets as mobile equipment and subject to the new standards.

[E] Note that, while >750 hp mobile machine engines are not expected to add a NOx adsorber to comply with the new engine standards, we have considered that the corporate R&D conducted for engines expected to add both a NOx adsorber and a CDPF will apply for engines >750 hp given the general similarity between large engines above and below manufacturers will 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), and the light-duty and heavy-duty diesel requirements in Europe. This learning may come from seminars, conferences, technical publications regarding diesel engine technology (e.g., Society of Automotive Engineers technical papers), and contact with highway manufacturers, emission-control device manufacturers, and the independent engine research laboratories conducting relevant R&D. Therefore, we have estimated an average expenditure of 70 percent of that spent by highway manufacturers in their highway efforts. This lower number—$25.3 million versus $36.1 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. This value does not include the engine line R&D.

Note that the $3.6 million and $25.3 million estimates represent our estimate of the average corporate R&D expected by manufacturers. Each manufacturer may have more or less than these average figures.

For manufacturers selling smaller engines that we project will add only a CDPF (i.e., 25 to 75 hp engines in 2013), we have estimated that their average R&D will 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 is not appropriate. Using this estimate, the average corporate R&D incurred by manufacturers that already have been selling engines into both the highway and the nonroad markets will be $1.2 million not including engine line R&D, and the average corporate R&D for manufacturers selling engines only into the nonroad market will be roughly $8.3 million not including engine line R&D. All this R&D is attributed to PM control.

For manufacturers selling engines that will add only a DOC or will make only some engine-out modification (i.e., to meet the PM standard for engines under 75 hp in 2008), we have estimated that their average corporate R&D will 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 used for years and because they require no special fueling strategies or operating conditions to operate properly. Nonetheless, to avoid underestimating costs, we have estimated that the R&D incurred by manufacturers selling any engines into both the highway and nonroad markets will be roughly $600,000 not including engine line R&D, and the corporate R&D for manufacturers selling engines only into the nonroad market will be roughly $4.2 million not including engine line R&D. Because these R&D expenditures are strictly for meeting a PM standard, they are fully attributed to PM control.

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

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750 hp. We have included additional engine line R&D for all engines, including those >750hp, that is unique from this corporate R&D estimate.

Table 6.2-1
Estimated Corporate R&D Expenditures by Type of Manufacturer
Totals per Manufacturer over Five Years
($Million)

	R&D for DOC/engine-out Engines	R&D for CDPF&NOx Adsorber Engines	R&D for CDPF-only Engines
Horsepower range	0<hp<75	hp≥75	25≤hp<75
For new standards starting in year:	2008	2011 (175-750hp) 2012 (75-175hp) 2015 (>750hp)	2013
Manufacturer sells into both highway and nonroad markets	$0.6	$3.6	
Manufacturer sells only into the nonroad market	$4.2	$25.3	
Manufacturer has already done CDPF&NOx Adsorber R&D			$1.2
Manufacturer has not done CDPF&NOx Adsorber R&D			$8.3
% Allocated to PM	100%	33%	100%
% Allocated to NOx		67%	

Some manufacturers may actually incur more than one of the corporate R&D amounts shown in Table 6.2-1. For example, we would estimate that a manufacturer with engines in both the 25-75 hp range and the 175-750 hp range that sells only into the nonroad market would incur $30.7 million ($4.2 + $25.3 + $1.2). Likewise, we would estimate that a manufacturer with engines only in the 25-75 hp range that sells only into the nonroad market would incur $8.3 million. This way, we have estimated a unique corporate R&D expenditure for each manufacturer. To do this, we used certification data for the 2002 model year along with our best understanding of which manufacturers sell into both the highway and nonroad markets and which sell only into the nonroad market.[F]

[F] We have used the 2002 model year certification data for consistency with the analysis done for the proposal which was done at a time when the 2002 model year was the most recent year for which complete certification data was available. Throughout this analysis, we assume the manufacturers that certified engines for 2002 are the manufacturers that will be certifying engines to the new Tier 4 standards.

When certifying engines, manufacturers project the sales of each engine they certify.[G] Using the projected sales information, we were able to determine how many engine sales each manufacturer expects to have in each of the power categories of interest. As a result, not every manufacturer is expected to incur all the R&D costs shown in Table 6.2-1. For example, some manufacturers do not certify engines under 75 hp. Such a manufacturer will 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 will conduct no R&D themselves and will instead rely on their joint venture partner. This is true unless the parent company has no engine sales in the power 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 power categories that Caterpillar does not. As a result, we have attributed R&D costs to Caterpillar for conducting R&D that will benefit Perkins engines. We have identified nine manufacturers to whom we have attributed no R&D because of a joint partner agreement.[H] For some of these (such as Perkins), we have attributed R&D costs to their parent for the engines they will sell, and some are effectively the same company as their parent (for example, 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 will 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 the revenues they receive from engine sales to which the new NRT4 standards would apply.[I] 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.

[G] Projected sales information is confidential business information. We cannot present this information here nor can we present details of calculations that use projected sales data since back calculating could shed light on the projected sales data.

[H] 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 partners 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.

[I] 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 will 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; it would therefore not result in increased costs associated with the new emission standards.

sales volumes, we believe it is unlikely that they will conduct the necessary R&D themselves. Instead, they will probably license the technology from another manufacturer, which will 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. Determining which manufacturers will or will not invest in R&D is based on projected sales data, so we cannot share the manufacturers' names. It is important to note that the total projected sales for all three engine manufacturers was 77 engines in the 2002 model year.

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

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 corporate R&D expenditures are shown in Table 6.2-2.

Table 6.2-2
Estimated Industry-wide Corporate R&D Expenditures for the NRT4 Standards[a]

	DOC/engine-out R&D[b]	CDPF+NOx Adsorber R&D[b, c]	CDPF-only R&D[b]	Corporate R&D Total[b]
Expenditures during Years	2004-2007	2006-2014	2008-2012	2004-2014
Horsepower	0<hp<75	≥75 hp	25≤hp<75	all hp
Total Industry-wide Corporate R&D Expenditures	$37.2	$121.8	$46.7	$205.7
Corporate R&D for PM	$37.2	$40.2	$46.7	$124.1
Corporate R&D for NOx	—	$81.6	—	$81.6

[a] Dollar values are in millions of 2002 dollars.
[b] Corporate R&D attributable to US sales resulting from this final rule (see discussion in text). Engine line R&D is presented in Table 6.2-3. Total R&D – corporate R&D plus engine line R&D – is presented in Table 6.2-4.
[c] This includes corporate R&D for >750 hp engines.

To this corporate R&D estimate, we have added an engine line R&D element. This engine line R&D will cover costs for a manufacturer to tailor the knowledge gained through corporate R&D to each particular engine line in their mix. Based on confidential comments submitted during the public comment period and our analysis of them, we have estimated these costs to be

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[J] 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.

$1 million for each engine line in the 25-75 hp range (to meet the 2013 standards), $3 million for each engine line from 75-750 hp, and $6 million for those engine lines over 750 hp. We have assumed no engine line R&D for <75 hp engines to meet the 2008 standards because we do not believe that the relatively simple addition of a DOC or the modifications impacting engine-out emissions will require such a R&D effort. We have determined the number of engine lines by considering that, typically, the same basic diesel engine design can be increased or decreased in size by simply adding or subtracting cylinders. As a result, a four-, six-, or eight-cylinder engine may be produced from the same basic engine design. While these engines have different total displacement, they each have the same displacement per cylinder. Using the PSR database, we grouped each engine manufacturer’s engines into distinct engine lines using increments of 0.5 liters per cylinder. This way, engines having similar displacements per cylinder are grouped together and are considered to be one engine line. Table 6.2-3 presents the number of engine lines for which we have estimated this engine line R&D expenditure along with the total industry-wide engine line R&D we have estimated.

Table 6.2-3
Estimated Industry-wide Engine Line R&D Expenditures for the NRT4 Standards[a]

Expenditures during Years	2008-2012	2006-2010	2007-2011	2010-2014	2006-2014
Horsepower	25<hp<75	175-750 hp	75≤hp<175	>750 hp	All
Engine Lines	21	52[b]	28	3	104
Engine Line R&D per Line	$1.0	$3.0	$3.0	$6.0	–
Engine Line R&D Total[c]	$8.8	$65.7	$35.4	$7.6	$117.5
Engine Line R&D for PM[c]	$8.8	$21.7	$11.7	$7.6	$49.8
Engine Line R&D for NOx[c]	–	$44.0	$23.7	–	$67.7

[a] Dollar values are in millions of 2002 dollars.
[b] This excludes 16 engine lines – those engine lines considered in the HD2007 rule. We have not included these highway engine lines since manufacturers will be conducting engine line R&D to meet the HD2007 standards.
[c] Dollar amounts shown here are those amounts attributable to US sales, as discussed in the main text.

We have estimated that all engine R&D expenditures—corporate R&D plus engine line R&D—occur over a five year span preceding the first year any emission-control device is introduced into the market. The one exception to this being corporate R&D done for the 2008 standards which would be incurred over a four year span beginning today. Those expenditures are then recovered by the engine manufacturer during any phase-in years and then over a five-year span following full introduction of the technology. Since PM standards take effect without a multi-year phase-in, 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 include a cost of seven percent when amortizing engine R&D expenditures.

Our R&D estimates represent the cost to develop advanced aftertreatment-based emission-control systems enabled by 15 ppm sulfur fuel. We are projecting that manufacturers will need to do this R&D to sell engines in Europe, Japan, Australia, and Canada because we expect that similar emission standards will be required in a similar time frame for each of these regions or countries.[8] Therefore, we have attempted to attribute the costs of R&D to the total 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 United States relative to these other regions, we have used Gross Domestic Product (GDP) as a surrogate for sales.[K,9] As a result, we have attributed only a portion of the R&D expenditures to engine sales within the United States. The United States' GDP is 42 percent of the total GDP from all the countries that are expected to adopt Tier 4 or similar emission standards for nonroad diesel engines.[L] Therefore, we have attributed 42 percent of the total R&D costs to U.S. sales.[M] Note that all engine R&D costs for <25 hp engines have been attributed to U.S. sales since other countries are not expected to have similar standards on these engines (though, as noted in the preamble for this final rule, the European Commission may revisit this issue in their 2007 Nonroad standards review).

The total estimated R&D attributable to US sales associated with the NRT4 engine standards—corporate R&D presented in Table 6.2-2 and engine line R&D presented in Table 6.2-3—is shown in Table 6.2-4.

[K] We considered using revenue and income data for nonroad engine/equipment companies that might show what percent of those business metrics were US based versus non-US based. However, we were not able to find information on all of the more than 50 nonroad diesel engine companies and the more than 600 nonroad diesel equipment companies. In fact, we were able to locate information on only 10 nonroad engine/equipment companies because many companies are not publicly traded in the US or do not present revenue and income data on a geographic basis. The results of our research are contained in a memorandum to the docket (see Charmley, April 7, 2004, EDOCKET OAR-2003-0012-0927). The limited data set generated by that research shows geographic distribution of revenue and income that is not inconsistent with our 42 percent distribution.

[L] 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 $7.8 trillion; Australia's GDP was $0.4 trillion; Canada's GDP was $0.7 trillion; Japan's GDP was $4.7 trillion; and the U.S. GDP was $9.9 trillion; for a total GDP of $23.5 trillion (www.worldbank.org).

[M] This is already factored into the costs shown in Tables 6.2-2 through 6.2-4, but is not factored into the costs shown in Table 6.2-1.

Table 6.2-4
Estimated Total R&D Expenditures for the NRT4 Standards[a]

	DOC/engine-out R&D[b]	CDPF+NOx Adsorber R&D[b, c]	CDPF-only R&D[b]	Total R&D[b]
Expenditures during Years	2004-2007	2006-2014	2008-2012	2004-2014
Horsepower	0<hp<75	≥75 hp	25≤hp<75	all hp
Total Industry-wide R&D Expenditures[c]	$37.2	$230.5	$55.5	$323.2
Total R&D for PM[c]	$37.2	$81.2	$55.5	$173.9
Total R&D for NOx[c]	—	$149.3	—	$149.3

[a] Dollar values are in millions of 2002 dollars.
[b] Total R&D – corporate R&D plus engine line R&D.
[c] Dollar amounts shown here are those amounts attributable to US sales, as discussed in the main text.

We have weighted R&D recovery according to estimated revenues for engines sold in each power category. For example, CDPF&NOx Adsorber R&D benefits all engines over 75 hp. However, we have assumed that engines in the 175-750 hp range must introduce the new technologies in 2011, while engines from 75 to 175 hp will introduce it a year later. As a result, R&D costs are assumed to be recovered on engines in the 175-750 hp range between 2011 and 2015/2018 and on 75 to 175 hp engines between 2012 and 2016/2018. R&D costs for >750 hp engines are assumed to be recovered between 2015-2019. 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 will 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 6.2-5.

Using this methodology, we have estimated the total R&D expenditures associated with the new emission standards to vary from $9 to $57 million per year, with an average of $27 million per year and a total of $323 million. Total R&D recovery on U.S. sales is estimated at $452 million. All estimated R&D costs are shown in Table 6.2-6. Note that the engine sales numbers shown in Table 6.2-6 are discussed in greater detail in Chapter 8, where we present aggregate costs to society.

Table 6.2-5
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	2015-2019
			NOx	N/A	2011-2018	2012-2018	N/A	N/A
0<hp<25	119,159	$1,500		22%				
25≤hp<50	132,981	$2,900		46%			59%	
50≤hp<75	93,914	$2,900		32%			41%	
75≤hp<100	68,665	$5,200				12%		
100≤hp<175	112,340	$5,200				19%		
175≤hp<300	61,851	$10,300			30%	21%		
300≤hp<600	34,095	$31,000			49%	34%		
600≤hp≤750	2,752	$80,500			10%	7%		
hp>750	2,785	$80,500			11%	7%		100%
Total	628,542			100%	100%	100%	100%	100%

Table 6.2-6

Estimated R&D Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2002

Millions of dollars, except engine sales and per engine costs

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	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	197,363	
	PM Costs Incurred		$2.0	$2.0	$2.0	$2.0													$8.2
	NOx Costs Incurred																		$0.0
	PM Costs Recovered						$2.2	$2.2	$2.2	$2.2	$2.2								$11.0
	NOx Costs Recovered																		$0.0
	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	199,576	
	PM Costs Incurred		$4.3	$4.3	$4.3	$4.3	$6.5	$6.5	$6.5	$6.5	$6.5								$49.6
	NOx Costs Incurred																		$0.0
	PM Costs Recovered						$4.6	$4.6	$4.6	$4.6	$4.6	$9.1	$9.1	$9.1	$9.1	$9.1			$68.7
	NOx Costs Recovered																		$0.0
	Per Engine Cost						$29	$28	$27	$27	$26	$51	$50	$49	$48	$47			
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	132,781	
	PM Costs Incurred		$3.0	$3.0	$3.0	$3.0	$4.6	$4.6	$4.6	$4.6	$4.6								$35.0
	NOx Costs Incurred																		$0.0
	PM Costs Recovered						$3.3	$3.3	$3.3	$3.3	$3.3	$6.5	$6.5	$6.5	$6.5	$6.5			$48.5
	NOx Costs Recovered																		$0.0
	Per Engine Cost						$29	$29	$28	$28	$27	$54	$53	$52	$51	$50			
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	97,151	
	PM Costs Incurred					$1.5	$1.5	$1.5	$1.5	$1.5									$7.7
	NOx Costs Incurred					$1.6	$1.6	$3.1	$3.1	$3.1	$1.6	$1.6							$15.6
	PM Costs Recovered										$2.2	$2.2	$2.2	$2.2	$2.2				$10.8
	NOx Costs Recovered										$2.2	$2.2	$4.4	$4.4	$4.4	$2.2	$2.2		$21.8
	Per Engine Cost										$50	$49	$73	$72	$70	$23	$23		
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	156,441	
	PM Costs Incurred					$2.5	$2.5	$2.5	$2.5	$2.5									$12.5
	NOx Costs Incurred					$2.5	$2.5	$5.1	$5.1	$5.1	$2.5	$2.5							$25.5
	PM Costs Recovered										$3.5	$3.5	$3.5	$3.5	$3.5				$17.6
	NOx Costs Recovered										$3.6	$3.6	$7.1	$7.1	$7.1	$3.6	$3.6		$35.7
	Per Engine Cost										$51	$50	$74	$72	$71	$24	$23		
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	88,717	
	PM Costs Incurred				$3.3	$3.3	$3.3	$3.3	$3.3										$16.7
	NOx Costs Incurred				$3.6	$3.6	$3.6	$7.2	$7.2	$3.6	$3.6	$3.6							$36.1
	PM Costs Recovered									$4.7	$4.7	$4.7	$4.7	$4.7					$23.4
	NOx Costs Recovered									$5.1	$5.1	$5.1	$10.1	$10.1	$5.1	$5.1	$5.1		$50.6
	Per Engine Cost									$126	$124	$121	$181	$178	$60	$59	$58		
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	42,379	
	PM Costs Incurred				$5.5	$5.5	$5.5	$5.5	$5.5										$27.6
	NOx Costs Incurred				$6.0	$6.0	$6.0	$11.9	$11.9	$6.0	$6.0	$6.0							$59.7
	PM Costs Recovered									$7.7	$7.7	$7.7	$7.7	$7.7					$38.7
	NOx Costs Recovered									$8.4	$8.4	$8.4	$16.7	$16.7	$8.4	$8.4	$8.4		$83.7
	Per Engine Cost									$414	$410	$405	$609	$602	$204	$202	$200		
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	3,702	
	PM Costs Incurred				$1.2	$1.2	$1.2	$1.2	$1.2										$5.8
	NOx Costs Incurred				$1.3	$1.3	$1.3	$2.5	$2.5	$1.3	$1.3	$1.3							$12.5
	PM Costs Recovered									$1.6	$1.6	$1.6	$1.6	$1.6					$8.1
	NOx Costs Recovered									$1.8	$1.8	$1.8	$3.5	$3.5	$1.8	$1.8	$1.8		$17.6
	Per Engine Cost									$1,023	$1,007	$993	$1,487	$1,465	$494	$487	$481		
>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	3,754	
	PM Costs Incurred				$0.7	$0.7	$0.7	$0.7	$2.2	$1.5	$1.5	$1.5	$1.5						$10.9
	NOx Costs Incurred																		$0.0
	PM Costs Recovered									$0.9	$0.9	$0.9	$0.9	$3.1	$2.1	$2.1	$2.1	$2.1	$15.3
	NOx Costs Recovered																		$0.0
	Per Engine Cost									$278	$274	$270	$266	$861	$591	$582	$574	$567	
All hp	PM Costs Incurred		$9.3	$9.3	$20.0	$24.0	$25.8	$25.8	$27.3	$16.7	$12.6	$1.5	$1.5						$173.9
	NOx Costs Incurred				$10.8	$14.9	$14.9	$29.9	$29.9	$19.0	$14.9	$14.9							$149.3
	Total Costs Incurred		$9.3	$9.3	$30.8	$38.9	$40.8	$55.7	$57.2	$35.7	$27.6	$16.5	$1.5						$323.2
	PM Costs Recovered						$10.1	$10.1	$10.1	$25.0	$30.7	$36.2	$36.2	$38.3	$23.4	$17.7	$2.1	$2.1	$242.1
	NOx Costs Recovered									$15.2	$20.9	$20.9	$41.9	$41.9	$26.7	$20.9	$20.9		$209.5
	Total Costs Recovered						$10.1	$10.1	$10.1	$40.2	$51.6	$57.2	$78.1	$80.2	$50.1	$38.7	$23.1	$2.1	$451.5

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 HD2007 rule, we estimated approximately $1.6 million per engine line for tooling costs associated with CDPF/NOx adsorber systems. For the Tier 4 standards, we have estimated that nonroad-only manufacturers will incur the same amount – $1.65 million expressed in 2002 dollars – for each engine line that requires a CDPF/NOx adsorber system. These costs are assigned equally to NOx control and PM control. We have estimated the same tooling costs as in the HD2007 rule because we expect Tier 4 engines to use the same technologies (i.e., a CDPF and a NOx adsorber). For those systems requiring only a CDPF, we have estimated one-half that amount, or $825,000 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 $412,500 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 $1.65 million baseline discussed above. For those engines requiring a CPDF/NOx adsorber system (i.e., those over 75 hp) we have adjusted that $1.65 million baseline by 50 percent. We believe this 50 percent adjustment is reasonable since many nonroad engines over 75 hp are produced on the same engine line with their highway counterparts. For such lines, tooling costs will be negligible. For engine lines without a highway counterpart, the $1.65 million tooling cost applies. For highway manufacturers selling into both the highway and the nonroad markets, we have estimated a 50/50 split of nonroad engine product lines (i.e., 50 percent with highway counterparts and 50 percent without) and therefore applied a 50 percent factor to the $1.65 million baseline. These tooling costs are split evenly between NOx control and PM control. For those engine lines requiring only a CDPF (i.e., those between 25 and 75 hp), we have estimated the same tooling cost as used for nonroad-only manufacturers, or $825,000. Similarly, the tooling costs for DOC and/or engine-out engine lines has been estimated to be $412,500. We have used the same tooling costs as the nonroad-only manufacturers for engines under 75 hp 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 project that engines between 25 and 50 hp will apply EGR systems to meet the new NOx standards for 2013. For these engines, we have included an additional tooling cost of $41,300 per engine line, consistent with the EGR-related tooling cost estimated for 50 to 100 hp engines in our Tier 2/Tier 3 rulemaking which specified the same NOx standards. This tooling cost is applied equally to all engine lines in that power range, regardless of the markets into which the manufacturer sells. We have applied this tooling cost equally because engines in this power range do not tend to have highway counterparts. We expect EGR systems to be added to engines between 25 and 50 hp to meet the new NOx standard, so tooling costs for EGR systems are attributed solely to NOx control.

We have also estimated some tooling costs for >750 horsepower engines to meet the 2011 standards. We have estimated this amount at ten times the amount for 25 to 50 horsepower engines, or $413,000 per engine line. This cost was not in the proposal since NOx adsorbers were being projected for all >750 horsepower engines. We have applied this tooling to all engine lines >750 horsepower, regardless of what markets into which a manufacturer sells, since such engines clearly have no highway counterpart. We have attributed this cost to NOx control.

Tooling costs per engine line and type of manufacturer are summarized in Table 6.2-7.

Table 6.2-7
Estimated Tooling Expenditures per Engine Line by Type of Manufacturer[a]

	DOC/engine-out Engines	CDPF-only Engines	CDPF and NOx Adsorber Engines	EGR Engines[b]	EGR Engines
Horsepower range	0<hp<75	25≤hp<75	75≤hp<750	>750hp	25≤hp<50
For new standards starting in	2008	2013	2011/2012	2011	2013
Manufacturer sells into both highway and nonroad markets	$412,500	$825,000	$825,000	$413,000	$41,300
Manufacturer sells only into the nonroad market	$412,500	$825,000	$1,650,000	$413,000	$41,300
% Allocated to PM	100%	100%	50%	0%	0%
% Allocated to NOx	0%	0%	50%	100%	100%

[a] Dollar values are in millions of 2002 dollars.
[b] To remain conservative in our cost estimate, we have assumed that all engines >750hp add cooled EGR in 2011. We would expect manufacturers to use a less costly means of control if it allows them to meet the new standard (see section 4.1.2 of this RIA for more information regarding our estimates of EGR use).

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-, or eight-cylinder engine may be produced from the same basic engine design. While these engines have different total displacement, they each have the same displacement per cylinder. Using the PSR database, we grouped each engine manufacturer's engines into distinct engine lines using increments of 0.5 liters per cylinder. This way, engines having similar displacements per cylinder are grouped together and are considered to be built on the same production line. Note that a tooling expenditure for a single engine line may cover engines over several power categories. To allocate the tooling expenditure for a given production line to a specific power range, we have used sales-weighting within that engine line.

We have applied the above tooling costs to all manufacturers that appear to actually make engines. We have not eliminated joint venture manufacturers because these manufacturers 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 only into 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; tooling costs for <25 hp engines are attributed only to US sales since other countries are not expected to have similar standards on <25 hp engines. All tooling costs are assumed to be incurred one year before the standard they support and are then recovered over a five-year period following introduction of the new standard. We include a cost of seven percent when amortizing engine tooling costs.

Using this methodology, we estimate the total tooling expenditures attributable to this final rule at $74 million. Total tooling recovery on U.S. sales is estimated at $91 million. All estimated tooling costs are shown in Table 6.2-8.

Table 6.2-8

Estimated Tooling Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2002

Millions of dollars, except engine sales and per engine costs

		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	197,363	
	PM Costs Incurred	$5.2													$5.2
	NOx Costs Incurred														$0.0
	PM Costs Recovered		$1.3	$1.3	$1.3	$1.3	$1.3								$6.4
	NOx Costs Recovered														$0.0
	Per Engine Cost		$8	$8	$8	$8	$8								
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	199,576	
	PM Costs Incurred	$5.9					$4.3								$10.1
	NOx Costs Incurred						$0.5								$0.5
	PM Costs Recovered		$1.4	$1.4	$1.4	$1.4	$1.4	$1.0	$1.0	$1.0	$1.0	$1.0			$12.4
	NOx Costs Recovered							$0.1	$0.1	$0.1	$0.1	$0.1			$0.6
	Per Engine Cost		$9	$9	$9	$8	$8	$7	$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	132,781	
	PM Costs Incurred	$4.1					$3.0								$7.2
	NOx Costs Incurred														$0.0
	PM Costs Recovered		$1.0	$1.0	$1.0	$1.0	$1.0	$0.7	$0.7	$0.7	$0.7	$0.7			$8.7
	NOx Costs Recovered														$0.0
	Per Engine Cost		$9	$9	$9	$9	$9	$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	97,151	
	PM Costs Incurred					$2.8									$2.8
	NOx Costs Incurred					$2.8									$2.8
	PM Costs Recovered						$0.7	$0.7	$0.7	$0.7	$0.7				$3.4
	NOx Costs Recovered						$0.7	$0.7	$0.7	$0.7	$0.7				$3.4
	Per Engine Cost						$16	$15	$15	$15	$15				
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	156,441	
	PM Costs Incurred					$4.5									$4.5
	NOx Costs Incurred					$4.5									$4.5
	PM Costs Recovered						$1.1	$1.1	$1.1	$1.1	$1.1				$5.5
	NOx Costs Recovered						$1.1	$1.1	$1.1	$1.1	$1.1				$5.5
	Per Engine Cost						$16	$16	$15	$15	$15				
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	88,717	
	PM Costs Incurred				$11.0										$11.0
	NOx Costs Incurred				$11.0										$11.0
	PM Costs Recovered					$2.7	$2.7	$2.7	$2.7	$2.7					$13.4
	NOx Costs Recovered					$2.7	$2.7	$2.7	$2.7	$2.7					$13.4
	Per Engine Cost					$69	$68	$67	$66	$65					
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	42,379	
	PM Costs Incurred				$6.1										$6.1
	NOx Costs Incurred				$6.1										$6.1
	PM Costs Recovered					$1.5	$1.5	$1.5	$1.5	$1.5					$7.4
	NOx Costs Recovered					$1.5	$1.5	$1.5	$1.5	$1.5					$7.4
	Per Engine Cost					$76	$75	$74	$74	$73					
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	3,702	
	PM Costs Incurred				$0.5										$0.5
	NOx Costs Incurred				$0.5										$0.5
	PM Costs Recovered					$0.1	$0.1	$0.1	$0.1	$0.1					$0.6
	NOx Costs Recovered					$0.1	$0.1	$0.1	$0.1	$0.1					$0.6
	Per Engine Cost					$72	$71	$70	$69	$68					
>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	3,754	
	PM Costs Incurred								$1.0						$1.0
	NOx Costs Incurred				$0.5										$0.5
	PM Costs Recovered									$0.3	$0.3	$0.3	$0.3	$0.3	$1.3
	NOx Costs Recovered					$0.1	$0.1	$0.1	$0.1	$0.1					$0.6
	Per Engine Cost					$38	$37	$37	$36	$107	$71	$70	$69	$68	
All hp	PM Costs Incurred	$15.2			$17.6	$7.3	$7.3		$1.0						$48.4
	NOx Costs Incurred				$18.1	$7.3	$0.5								$25.9
	Total Costs Incurred	$15.2			$35.6	$14.6	$7.8		$1.0						$74.3
	PM Costs Recovered		$3.7	$3.7	$3.7	$8.0	$9.8	$7.8	$7.8	$8.1	$3.8	$2.0	$0.3	$0.3	$59.1
	NOx Costs Recovered					$4.4	$6.2	$6.3	$6.3	$6.3	$1.9	$0.1			$31.6
	Total Costs Recovered		$3.7	$3.7	$3.7	$12.4	$16.0	$14.2	$14.2	$14.4	$5.7	$2.2	$0.3	$0.3	$90.6

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 using new test procedures. 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.[10] The $60,000 certification cost per engine family was used for engines in the 25 to 75 hp range certifying to the 2008 standards. For 25 to 75 hp engines certifying to the 2013 standards, and for 75-750 hp engines certifying to the appropriate standards, we have added costs to cover the new test procedures for nonroad diesel engines (i.e., the transient test and the NTE);[N] these costs were estimated at $31,500 per engine family. For engines >750 hp, the certification costs used were $87,000 per family since these engines will not be certifying over the new transient test procedure. For engines <25 hp, we have assumed (for cost purposes) that all engines will certify to the transient test and the NTE in 2008. We believe manufacturers may choose to do this rather than certifying all engines again in 2013 when the transient test and NTE requirements actually begin for those engines (and the rules explicitly provide the option of certifying these engines starting in 2008 using these tests). This assumption results in higher certification costs in 2008 than if these engines certified only to the steady-state standard. However, we believe manufacturers may choose to do this because it would avoid the need to recertify all <25 hp engines again in 2013. Certification costs (for engines in all hp ranges) 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 power rating of each. We grouped those power ratings into the nine ranges shown in Table 6.2-9. We have chosen these nine power categories because: (1) phasing in standards and having different levels of baseline and complying emission levels force such breakouts; and, (2) greater stratification (i.e., breaking up the 75 to 175 hp range and the 175 to 750 hp 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 new emission standards in the final rule. Table 6.2-9 shows the number of engine families in each power range and the year for they are subject to new emission standards, along with the total certification expenditures for those standards.

The cost expenditures shown in Table 6.2-9 are estimated to occur one year before the year shown in the table. The years shown in the table coincide with the years for which the new standards begin, thereby requiring engine certification. Half the 175 to 750 hp engine families

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[N] Note that the transport refrigeration unit (TRU) test cycle is an optional duty cycle for steady-state certification testing specifically tailored to the operation of TRU engines. Likewise, the ramped modal cycles are available test cycles that can be used to replace existing steady-state test requirements for nonroad constant-speed engines, generally. Manufacturers of these engines who opt to use one of these test cycles would incur no new costs above those estimated here and may incur less cost.

certified for 2011 must again be certified in 2014 when the NOx phase-in becomes 100 percent. For 25 to 50 hp engines in 2013, half the certification costs are attributed to PM and half are attributed to NOx, due to the new PM and NOx standards for those engines in that year; all the certification costs for 50 to 75 hp engine families are attributed to PM because only a new PM standard applies in that year for those engines.

Note that these certification costs may overestimate actual costs because they assume all engines are certified as a result of the new emission standards in this final rule. However, some engines would have been scheduled for new certification independent of this final rule due to design changes or power increases among other possible reasons. For such engines, the incremental certification cost would be those costs associated with the new test procedures and would not include certification costs associated with the existing test procedure. However, to remain conservative, here we have applied the full certification costs to all engine families. Given the magnitude of certification costs relative to other costs in this final rule, this has little impact on the costs per ton of emissions reduced or the cost/benefit results.

Table 6.2-9
Number of Engine Families, Estimated
Certification Costs, and Allocation of Certification Costs[a]

Power range	Model Year for New Emission Standards							
	2008	2011	2012	2013		2014		2015
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]		40						40
Total families	322	215	128	132	88	88	64	40
Total Cert Costs	$22.5	$19.5	$11.7	$12.1	$8.1	$8.0	$5.9	$3.5
% Allocated to PM	100%	50%	50%	50%	100%	0%	0%	50%
% Allocated to NOx	0%	50%	50%	50%	0%	100%	100%	50%

[a] Dollar values are in millions of 2002 dollars.

To estimate recovery of certification expenditures, we have attributed the expenditures to engines sold in the specific power range and spread the recovery of costs over U.S. sales within that category. Expenditures are incurred one year before the emission standard for which the certification is conducted, and are then recovered over a five-year period following the certification. We include a cost of seven percent when amortizing engine certification costs. We have spread these certification costs only over the engines sold in the United States because U.S. EPA certification is not presumed to fulfill the certification requirements of other countries. Total certification expenditures are estimated at $91 million. Recovery of certification costs is estimated at $111 million. All estimated certification expenditures and the recovery of those expenditures are shown in Table 6.2-10.

Table 6.2-10

Estimated Certification Costs Incurred (Non-Annualized) and Recovered (Annualized) -- expressed in $2002

Millions of dollars, except engine sales and per engine costs

		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	197,363	
	PM Costs Incurred	$9.3													$9.3
	NOx Costs Incurred														$0.0
	PM Costs Recovered		$2.3	$2.3	$2.3	$2.3	$2.3								$11.4
	NOx Costs Recovered														$0.0
	Per Engine Cost		$15	$15	$14	$14	$14								
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	199,576	
	PM Costs Incurred	$7.9					$6.0								$14.0
	NOx Costs Incurred						$6.0								$6.0
	PM Costs Recovered		$1.9	$1.9	$1.9	$1.9	$1.9	$1.5	$1.5	$1.5	$1.5	$1.5			$17.0
	NOx Costs Recovered							$1.5	$1.5	$1.5	$1.5	$1.5			$7.4
	Per Engine Cost		$12	$12	$11	$11	$11	$16	$16	$16	$16	$15			
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	132,781	
	PM Costs Incurred	$5.3					$8.1								$13.3
	NOx Costs Incurred														$0.0
	PM Costs Recovered		$1.3	$1.3	$1.3	$1.3	$1.3	$2.0	$2.0	$2.0	$2.0	$2.0			$16.3
	NOx Costs Recovered														$0.0
	Per Engine Cost		$12	$11	$11	$11	$11	$16	$16	$16	$16	$15			
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	97,151	
	PM Costs Incurred					$2.5									$2.5
	NOx Costs Incurred					$2.5		$2.2							$4.7
	PM Costs Recovered						$0.6	$0.6	$0.6	$0.6	$0.6				$3.1
	NOx Costs Recovered						$0.6	$0.6	$1.2	$1.2	$1.2	$0.5	$0.5		$5.8
	Per Engine Cost						$14	$14	$20	$19	$19	$6	$6		
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	156,441	
	PM Costs Incurred					$3.3									$3.3
	NOx Costs Incurred					$3.3		$3.6							$7.0
	PM Costs Recovered						$0.8	$0.8	$0.8	$0.8	$0.8				$4.1
	NOx Costs Recovered						$0.8	$0.8	$1.7	$1.7	$1.7	$0.9	$0.9		$8.5
	Per Engine Cost						$12	$11	$17	$17	$17	$6	$6		
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	88,717	
	PM Costs Incurred				$4.7										$4.7
	NOx Costs Incurred				$4.7			$5.0							$9.7
	PM Costs Recovered					$1.1	$1.1	$1.1	$1.1	$1.1					$5.7
	NOx Costs Recovered					$1.1	$1.1	$1.1	$2.4	$2.4	$1.2	$1.2	$1.2		$11.8
	Per Engine Cost					$29	$29	$28	$43	$42	$14	$14	$14		
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	42,379	
	PM Costs Incurred				$2.9										$2.9
	NOx Costs Incurred				$2.9			$2.8							$5.7
	PM Costs Recovered					$0.7	$0.7	$0.7	$0.7	$0.7					$3.6
	NOx Costs Recovered					$0.7	$0.7	$0.7	$1.4	$1.4	$0.7	$0.7	$0.7		$6.9
	Per Engine Cost					$37	$36	$36	$52	$52	$16	$16	$16		
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	3,702	
	PM Costs Incurred				$0.4										$0.4
	NOx Costs Incurred				$0.4			$0.2							$0.6
	PM Costs Recovered					$0.1	$0.1	$0.1	$0.1	$0.1					$0.5
	NOx Costs Recovered					$0.1	$0.1	$0.1	$0.2	$0.2	$0.1	$0.1	$0.1		$0.8
	Per Engine Cost					$61	$60	$59	$74	$73	$15	$15	$15		
>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	3,754	
	PM Costs Incurred				$1.7				$1.7						$3.5
	NOx Costs Incurred				$1.7				$1.7						$3.5
	PM Costs Recovered					$0.4	$0.4	$0.4	$0.4	$0.8	$0.4	$0.4	$0.4	$0.4	$4.2
	NOx Costs Recovered					$0.4	$0.4	$0.4	$0.4	$0.8	$0.4	$0.4	$0.4	$0.4	$4.2
	Per Engine Cost					$254	$250	$246	$243	$478	$236	$232	$229	$226	
All hp	PM Costs Incurred	$22.5			$9.7	$5.9	$14.1		$1.7						$54.0
	NOx Costs Incurred				$9.7	$5.9	$6.0	$13.9	$1.7						$37.2
	Total Costs Incurred	$22.5			$19.5	$11.7	$20.1	$13.9	$3.5						$91.2
	PM Costs Recovered		$5.5	$5.5	$5.5	$7.9	$9.3	$7.2	$7.2	$7.7	$5.3	$3.9	$0.4	$0.4	$65.8
	NOx Costs Recovered					$2.4	$3.8	$5.3	$8.7	$9.1	$6.7	$5.3	$3.8	$0.4	$45.4
	Total Costs Recovered		$5.5	$5.5	$5.5	$10.2	$13.1	$12.5	$15.9	$16.7	$12.0	$9.1	$4.2	$0.8	$111.2

6.2.2 Engine Variable Costs

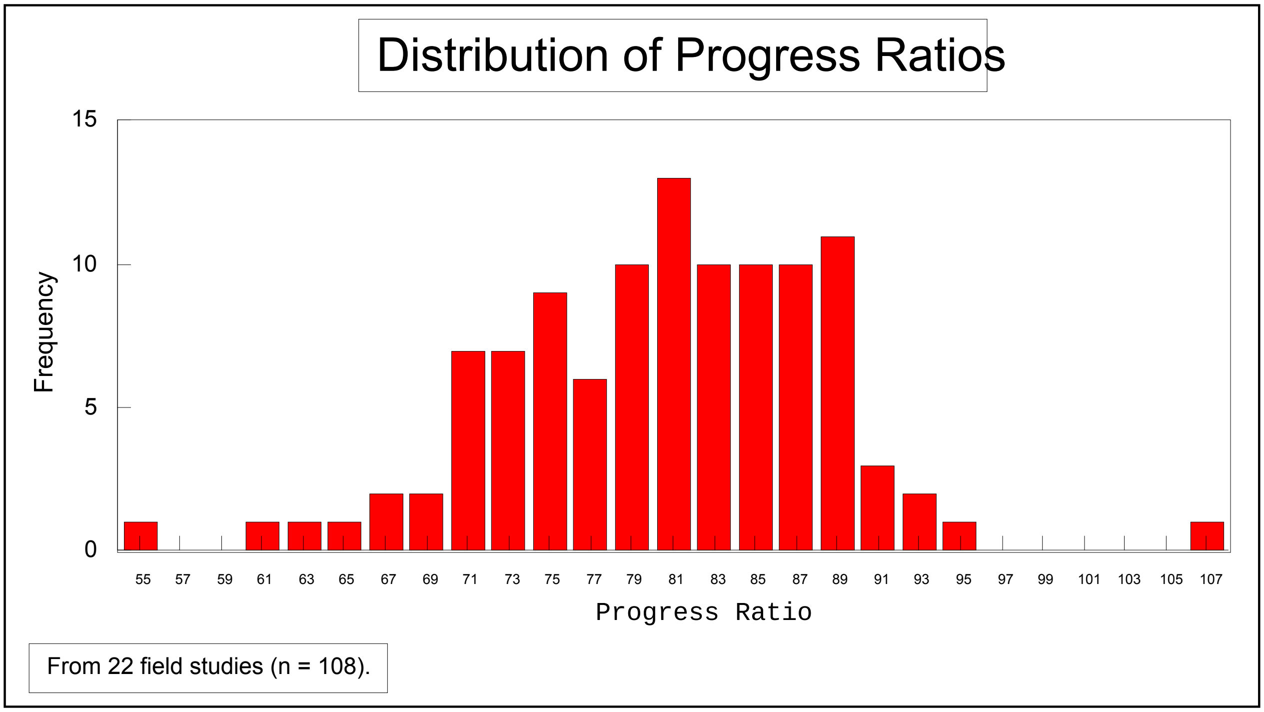
Engine variable costs are those costs for new hardware required to meet the new emission standards. In this section, we present our estimates of engine variable costs. Because of the wide variation of engine sizes in the nonroad market, we have chosen an approach that results not in a specific cost per engine for engines within a given power 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 power 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 power range unless the range is kept very small. To state an average variable cost for a range such as 175 to 300 hp is far less precise than what we present here. Using the equations presented in this section, we have then estimated the engine variable costs for certain specific pieces of equipment and for the sales weighted average piece of equipment. These estimates can be found in Section 6.5.

The discussion here considers both near-term and long-term cost estimates. We believe there are factors that 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.[11]

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

Companies and industry sectors learn differently. In a 1984 publication, Dutton and Thomas reviewed the progress ratios for 108 manufactured items from 22 separate field studies representing a variety of products and services.[12] 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



From 22 field studies (n = 108).

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

We believe the learning curve is appropriate to consider in assessing the cost impact of diesel engine emission controls. The learning curve applies to new technology, new manufacturing operations, new parts, and new assembly operations. Nonroad diesel engines currently do not use any form of NOx aftertreatment and have used diesel particulate filters only in limited application. These are therefore 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, we believe 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. We believe a similar opportunity exists for the new control systems that will integrate the function of the engine and 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 electronic fuel systems including common rail systems— they will be applied in some new ways in response to the Tier 4 standards. Additionally some new components will be applied for the first time. These new parts and new assemblies will involve new manufacturing operations. As manufacturers gain experience with these new systems, comparable learning is expected to occur with respect to unit labor and material costs. These changes require manufacturers to start new production procedures, which will improve with experience.

We have applied a p value of 80 percent beginning with the first year of introduction of any new technology. That is, variable costs were reduced by 20 percent for each doubling of cumulative production following the year in which the technology was first introduced in a given power range of engines. This way, learning is applied at the start of 2013 for engines over 175 hp and in 2014 for engines between 75 to 175 hp 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 emission standards in this final rule follows that 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 for highway engines serves as the baseline level of learning for nonroad engines. 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 occurs 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 is less opportunity for lowering production costs. For that reason, we applied only one learning curve effect. The situation is similar for nonroad engines. Because these will be existing technologies by the time they are introduced into the market, there would arguably be less opportunity for learning than there will be for the highway engines 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.[13] 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 anticipated for Tier 4 is the same technology as for highway applications. For the NOx adsorber to function properly, a systems approach that includes a reductant metering system and control of engine air-fuel ratio is also necessary. Many of the new air handling and electronic system technologies developed in order to meet the Tier 2/Tier 3 nonroad diesel 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 probably will 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 HD2007 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 6.2-11 and represent costs to the engine manufacturers inclusive of supplier markups. The manufacturer costs shown in Table 6.2-11 (as well as Tables 6.2-13 and 6.2-18 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 mark up the cost of the individual components within their products because those components consist of basic commodities (for example, precious metals used in the catalyst could not be arbitrarily marked up because of their commodity status). Instead, manufacturing entities could mark up costs only where they add a unique value to the product. In the case of catalyst systems, 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 (which is effectively specialized clays) serves to hold the catalytic metals in place and to control the surface area of the catalytic metals available for emission control. Although the 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.[14] Also included is our estimate of warranty costs for the NOx adsorber system.

Table 6.2-11. NOx Adsorber System Costs

	NOx Adsorber Costs ($2002)							
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	$12	$32	$38	$62	$147	$166	$282
Washcoating and Canning	$13	$52	$135	$162	$263	$620	$700	$1,189
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	$18	$18	$18
Direct Labor Costs								
Estimated Labor hours	2	2	2	2	2	2	2	2
Labor Rate ($/hr)	$30	$30	$30	$30	$30	$30	$30	$30
Labor Cost	$45	$45	$45	$45	$45	$60	$60	$60
Labor Overhead @ 40%	$18	$18	$18	$18	$18	$24	$24	$24
Total Direct Costs to Mfr.	$109	$210	$431	$502	$775	$1,747	$1,957	$3,254
Warranty Cost -- Near Term (3% claim rate)	$9	$17	$34	$39	$59	$131	$146	$244
Mfr. Carrying Cost -- Near Term	$4	$8	$17	$20	$31	$70	$78	$130
Total Cost to Dealer -- Near Term	$122	$235	$482	$561	$865	$1,948	$2,182	$3,628
Dealer Carrying Cost -- Near Term	$4	$7	$14	$17	$26	$58	$65	$109
DOC for cleanup -- Near Term	$105	$132	$192	$211	$286	$459	$497	$734
Baseline Cost to Buyer -- Near Term	$231	$375	$688	$789	$1,177	$2,465	$2,745	$4,471
Cost to Buyer w/ Highway learning -- Near Term	$206	$326	$589	$674	$999	$2,064	$2,295	$3,724
Warranty Cost -- Long Term (1% claim rate)	$3	$6	$11	$13	$20	$44	$49	$81
Mfr. Carrying Cost -- Long Term	$4	$8	$17	$20	$31	$70	$78	$130
Total Cost to Dealer -- Long Term	$116	$224	$459	$535	$826	$1,861	$2,084	$3,466
Dealer Carrying Cost -- Long Term	$3	$7	$14	$16	$25	$56	$63	$104
DOC for cleanup -- Long Term	$99	$125	$182	$201	$272	$437	$474	$700
Baseline Cost to Buyer -- Long Term	$219	$356	$656	$752	$1,123	$2,354	$2,621	$4,270
Cost to Buyer w/ Highway learning -- Long Term	$195	$310	$561	$642	$952	$1,970	$2,191	$3,556
Cost to Buyer w/ Nonroad learning -- Long Term	$176	$273	$485	$554	$816	$1,664	$1,848	$2,985

We have estimated the cost of this system based on information from several reports.[15, 16, 17] The individual estimates and assumptions used to estimate the cost for the system are documented in the following paragraphs.

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.[18] The respondents indicated that the catalyst volume for a NOx adsorber catalyst may range from 1.5 times the engine displacement to as much as 2.5 times the engine displacement based on current washcoat technology. Based on current lean burn gasoline catalyst designs and engineering judgment, 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.[19]

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 HD2007 rule. This cost estimate was based on a relationship developed for current heavy-duty gasoline catalyst substrates.[20] We have converted that value to $5.44 ($2002) using the PPI for Motor Vehicle Parts and Accessories, Catalytic Convertors.[21]

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).[22] By using a value-added component that accounts for fixed costs (including R&D), overhead, marketing and profits from likely suppliers of the technology, we can estimate this fraction of the cost for the technology apart from other components that are more widely available as commodities (e.g, precious metals and catalyst substrates). Based on conversations with MECA, we understand this element of the product to represent the catalyst manufacturer's value added and, therefore, their opportunity for markup. As a result, the washcoating and canning costs shown in Table 6.2-11 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 percent of that total and rhodium representing 10 percent. 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.[23]

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 percent for transition cones, plus 20 percent for scrappage (material purchased but unused in the final product) and a price of \$1.01 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into \$2002.[24]

NOx Adsorber Direct Labor

The direct labor costs for the catalyst are estimated based on an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[25]

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 hp engine shown in Table 6.2-11 is as follows:

$$[(\$3 + \$13 + \$16 + \$3 + \$1 + \$9)(2.5) + (\$50)(4\text{hours})](3\%) = \$9$$

NOx Adsorber Manufacturer and Dealer Carrying Costs

The manufacturer's carrying cost was estimated at 4 percent of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3 percent of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.[26]

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 below in Section 6.2.2.3. Important to note here is that the DOC costs shown in Table 6.2-11 are lower in the long term because of the lower warranty claim rate—three 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 6.2-11, we calculated a linear regression to determine the NOx adsorber system cost as a function of engine displacement. This way, the function can 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 6.2-12. Note that Table 6.2-11 shows NOx adsorber system costs for engines under 75 hp. We do not anticipate any engines under 75 hp will apply NOx adsorber systems to comply with the new emission standards. Nonetheless, the costs shown were used to generate the equations shown in Table 6.2-12. 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 6.2-12
NOx Adsorber System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)
$2002

Near-Term Cost Function	\$103(x) + \$183	R^2=0.9998
Long-Term Cost Function	\$83(x) + \$160	R^2=0.9997

Table 6.2-12 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 6.2-12 include costs for a clean-up DOC; results generated using the DOC cost estimation equations presented in Table 6.2-16 should *not* be added to results generated using the equations in Table 6.2-12 to determine NOx adsorber system costs.

6.2.2.2 Catalyzed Diesel Particulate Filter Costs

As with the NOx adsorber system, the anticipated CDPF system for Tier 4 is the same as that used for highway applications, except that we are projecting that some form of active regeneration system will be employed as a backup to the passive regeneration capability of the

CDPF. For the CDPF to function properly, a systems approach that includes a reductant metering system and control of engine air-fuel ratio is also necessary. Many of the new air handling and electronic fuel system technologies developed in order to meet the Tier 2/Tier 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 used in our HD2007 rulemaking (although here, for nonroad engines, we have included costs for a regeneration system that was not part of the cost estimate in the HD2007 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 6.2-13 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.[27]

Table 6.2-13. Catalyzed Diesel Particulate Filter (CDPF) System Costs

	Catalyzed Diesel Particulate Filter (CDPF) Costs ($2002)							
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	$36	$139	$364	$437	$710	$1,673	$1,886	$3,206
Washcoating and Canning	$13	$52	$135	$162	$263	$620	$700	$1,189
Platinum	$11	$42	$109	$130	$212	$499	$563	$956
Filter Can Housing	$7	$7	$7	$7	$10	$14	$14	$14
Differential Pressure Sensor	$46	$46	$46	$46	$46	$46	$93	$93
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)	$30	$30	$30	$30	$30	$30	$30	$30
Labor Cost	$60	$60	$60	$60	$60	$60	$120	$120
Labor Overhead @ 40%	$24	$24	$24	$24	$24	$24	$48	$48
Total Direct Costs to Mfr.	$198	$370	$746	$867	$1,326	$2,937	$3,424	$5,626
Warranty Cost -- Near Term (3% claim rate)	$12	$24	$53	$62	$96	$217	$247	$412
Mfr. Carrying Cost -- Near Term	$8	$15	$30	$35	$53	$117	$137	$225
Total Cost to Dealer -- Near Term	$218	$409	$828	$963	$1,475	$3,271	$3,808	$6,264
Dealer Carrying Cost -- Near Term	$7	$12	$25	$29	$44	$98	$114	$188
Savings by removing muffler	-$46	-$46	-$46	-$46	-$46	-$46	-$46	-$46
Baseline Cost to Buyer -- Near Term	$178	$375	$806	$945	$1,473	$3,323	$3,876	$6,405
Cost to Buyer w/ Highway learning -- Near Term	$142	$300	$645	$756	$1,178	$2,658	$3,101	$5,124
Warranty Cost -- Long Term (1% claim rate)	$4	$8	$18	$21	$32	$72	$82	$137
Mfr. Carrying Cost -- Long Term	$8	$15	$30	$35	$53	$117	$137	$225
Total Cost to Dealer -- Long Term	$210	$393	$793	$922	$1,411	$3,126	$3,643	$5,989
Dealer Carrying Cost -- Long Term	$6	$12	$24	$28	$42	$94	$109	$180
Savings by removing muffler	-$46	-$46	-$46	-$46	-$46	-$46	-$46	-$46
Baseline Cost to Buyer -- Long Term	$170	$359	$770	$903	$1,407	$3,174	$3,706	$6,122
Cost to Buyer w/ Highway learning -- Long Term	$136	$287	$616	$722	$1,125	$2,539	$2,965	$4,898
Cost to Buyer w/ Nonroad learning -- Long Term	$109	$229	$493	$578	$900	$2,031	$2,372	$3,918

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.[28] The respondents indicated that the particulate filter volume may 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 on the maximum allowable flow restriction for the engine. Generically, the filter size is inversely proportional to its resistance to flow (a larger filter is less restrictive than a similar smaller filter). In the 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

CDPFs can be made from a wide range of filter materials including wire mesh, sintered metals, fibrous media, or ceramic extrusions. The most common material used for CDPFs for heavy-duty diesel engines is cordierite. Here we have based our cost estimates on the use of silicon carbide (SiC) even though it is more expensive than other filter materials. In the HD2007 rule, we estimated that CDPFs will consist of a cordierite filter costing $30 per liter. To remain conservative in our cost estimates for nonroad applications, we have assumed the use of silicon carbide filters costing double that amount, or $60 per liter.[O] This cost is directly proportional to filter volume, which is proportional to engine displacement. This $60 value is then converted to $2002 using the PPI for Motor Vehicle Parts and Accessories, Catalytic Convertors.[29] The end result being a cost of $62 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 percent for transition cones, plus 20 percent for scrappage (material purchased but unused in the final product) and a price of $1.01 per pound for 18 gauge stainless steel as estimated in a contractor report to EPA and converted into $2002.[30]

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.[31] A PPI adjusted cost of $46 per sensor has been used in this analysis.

[O] Note that we are being especially conservative with respect to >750 horsepower mobile machines where we believe that manufacturers may in fact use a wire mesh substrate rather than the SiC substrate we have costed and, indeed, we have based the level of the 2015 PM standard on this use of wire mesh substrates. We have chosen to remain conservative in our cost estimates by assuming use of a SiC substrate for all engines.

CDPF Direct Labor

Consistent with the approach for NOx adsorber systems, the direct labor costs for the CDPF are estimated based on an estimate of the number of hours required for assembly and established labor rates. Additional overhead for labor was estimated as 40 percent of the labor rate.[32]

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 percent of the direct costs. This reflects primarily the costs of capital tied up in extra inventory, and secondarily the incremental costs of insurance, handling and storage. The dealer's carrying cost was estimated at 3 percent of the incremental cost, again reflecting primarily the cost of capital tied up in extra inventory.[33]

Savings Associated with Muffler Removal

CDPF retrofits are currently 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."[34] 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 $46. The $46 estimate is an average for all engines; the actual savings will be higher for some and lower for others.

CDPF System Cost Estimation Function

Using the example CDPF costs shown in Table 6.2-13, we calculated a linear regression to determine the CDPF system cost as a function of engine displacement. This way, the function can 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 6.2-14.

Table 6.2-14
CDPF System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)
$2002

Near-term Cost Function	\$146(x) + \$75	R^2=0.9997
Long-term Cost Function	\$112(x) + \$57	R^2=0.9997

The near-term and long-term costs shown in Table 6.2-14 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 (for example, 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.[35] The cost estimates developed by ICF for a CDPF regeneration system are summarized in Table 6.2-15.

Table 6.2-15.
CDPF Regeneration System – Costs to the Manufacturer

ICF Estimated Regeneration System Costs to Manufacturers ($2002)								
Horsepower	20	35	80	150	250	400	650	1000
Displacement (L)	1	2	3	6	8	10	16	24
CDPF Regeneration System Costs	\$265	\$279	\$293	\$384	\$408	\$431	\$530	\$676

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 6.2-16.

Table 6.2-16.
CDPF Regeneration System – Costs to the User

EPA Estimate of CDPF Regeneration System Costs ($2002)								
Horsepower	20	35	80	150	250	400	650	1000
Displacement (L)	1	2	3	6	8	10	16	24
CDPF Regeneration System Costs	$265	$279	$293	$384	$408	$431	$530	$676
Warranty Cost – Near Term (3% claim rate)	$23	$24	$25	$32	$34	$35	$43	$54
Mfr. Carrying Cost (4%) – Near Term	$11	$11	$12	$15	$16	$17	$21	$27
Total Cost to Dealer – Near Term	$298	$314	$330	$432	$458	$484	$593	$756
Dealer Carrying Cost (3%) – Near Term	$9	$9	$10	$13	$14	$15	$18	$23
Total Cost to Buyer – Near Term	$307	$323	$340	$445	$471	$498	$611	$779
Warranty Cost – Long Term (1% claim rate)	$8	$8	$8	$11	$11	$12	$14	$18
Mfr. Carrying Cost (4%)– Long Term	$11	$11	$12	$15	$16	$17	$21	$27
Total Cost to Dealer – Long Term	$283	$298	$313	$410	$435	$460	$565	$721
Dealer Carrying Cost (3%) – Long Term	$8	$9	$9	$12	$13	$14	$17	$22
Subtotal	$291	$307	$323	$423	$448	$474	$582	$742
Total Cost to Buyer – Long-Term w/ learning	$233	$246	$258	$338	$359	$379	$466	$594

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 6.2-16 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 6.2-16 to be representative of the costs for 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 will 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 are lower than for an IDI engine, we have estimated that the regeneration system costs for a DI engine are half of those presented in Table 6.2-16.

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 6.2-16, we calculated a linear regression to determine the CDPF regeneration system cost as a function of engine displacement. This way, the function can 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 6.2-17.

Table 6.2-17
CDPF Regeneration System Costs as a Function of
Engine Displacement (x represents engine displacement in liters)
$2002

IDI Engine	Near-term Cost Function	\$20(x) + \$293	R^2=0.9916
	Long-term Cost Function	\$16(x) + \$223	R^2=0.9916
DI Engine	Near-term Cost Function	\$10(x) + \$147	R^2=0.9916
	Long-term Cost Function	\$8(x) + \$111	R^2=0.9916

Note that these costs—either the IDI or the DI costs, depending on the type of engine—are incurred for any engine adding a CDPF. The near-term and long-term costs shown in Table 6.2-17 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. We have assumed that manufacturers may choose to apply a diesel oxidation catalyst (DOC) downstream of the NOx adsorber technology to control these potential products. The DOC serves 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 projected that engines under 75 hp will 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 6.2-18. 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 DOCs have been manufactured for a long enough time period such that learning has already taken place.

Table 6.2-18.
Diesel Oxidation Catalyst (DOC) Costs

	Diesel Oxidation Catalyst Costs ($2002)							
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	$21	$26	$42	$98	$110	$188
Washcoating and Canning	$61	$76	$107	$117	$155	$208	$220	$294
Platinum (5 g/ft3)	$1	$5	$12	$14	$24	$55	$63	$106
Catalyst Can Housing	$4	$4	$4	$4	$7	$15	$17	$30
Direct Labor Costs								
Estimated Labor hours	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Labor Rate ($/hr)	$30	$30	$30	$30	$30	$30	$30	$30
Labor Cost	$15	$15	$15	$15	$15	$15	$15	$15
Labor Overhead @ 40%	$6	$6	$6	$6	$6	$6	$6	$6
Total Direct Costs to Mfr.	$90	$114	$166	$182	$248	$398	$432	$638
Warranty Cost -- Near Term (3% claim rate)	$8	$10	$14	$15	$20	$31	$34	$49
Mfr. Carrying Cost -- Near Term	$4	$5	$7	$7	$10	$16	$17	$26
Total Cost to Dealer -- Near Term	$102	$128	$186	$205	$277	$445	$483	$713
Dealer Carrying Cost -- Near Term	$3	$4	$6	$6	$8	$13	$14	$21
Total Cost to Buyer -- Near Term	$105	$132	$192	$211	$286	$459	$497	$734
Warranty Cost -- Long Term (1% claim rate)	$3	$3	$5	$5	$7	$10	$11	$16
Mfr. Carrying Cost -- Long Term	$4	$5	$7	$7	$10	$16	$17	$26
Total Cost to Dealer -- Long Term	$96	$122	$177	$195	$264	$425	$460	$680
Dealer Carrying Cost -- Long Term	$3	$4	$5	$6	$8	$13	$14	$20
Total Cost to Buyer -- Long Term	$99	$125	$182	$201	$272	$437	$474	$700

DOC Cost Estimation Function

Similar to what was done for NOx adsorber systems and CDPFs, we used the example costs shown in Table 6.2-18 to determine a cost function with engine displacement as the dependent variable. This way, the function can 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 6.2-19. Note that the NOx adsorber cost estimation equations shown in Table 6.2-12 include costs for a clean-up DOC; results generated using the DOC cost estimation equations presented in Table 6.2-19 should *not* be added to results generated using the equations in Table 6.2-12 to determine NOx adsorber system costs.

Table 6.2-19
DOC Costs as a Function of
Engine Displacement (x represents engine displacement in liters)
$2002

Near-term Cost Function	$18(x) + $116	R^2=0.9944
Long-term Cost Function	$18(x) + $110	R^2=0.9944

6.2.2.5 Closed-Crankcase Ventilation (CCV) System Costs

Consistent with our HD2007 rule, we are removing the provision that allows turbocharged 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 turbocharged engines will force manufacturers to rely on engineered closed crankcase ventilation systems that filter oil from the blow-by gases before 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 6.2-20. These costs are incurred only by turbocharged engines.

Table 6.2-20.
Closed Crankcase Ventilation (CCV) System Costs

	Closed Crankcase Ventilation (CCV) System Costs ($2002)							
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	$28	$29	$34	$35	$41	$59	$64	$89
Warranty Cost -- Near Term (3% claim rate)	$5	$5	$6	$6	$6	$7	$8	$10
Mfr. Carrying Cost -- Near Term	$1	$1	$1	$1	$2	$2	$3	$4
Total Cost to Dealer -- Near Term	$34	$35	$41	$42	$48	$69	$74	$103
Dealer Carrying Cost -- Near Term	$1	$1	$1	$1	$1	$2	$2	$3
Total Cost to Buyer -- Near Term	$35	$36	$42	$44	$50	$71	$76	$106
Warranty Cost -- Long Term (1% claim rate)	$2	$2	$2	$2	$2	$2	$3	$3
Mfr. Carrying Cost -- Long Term	$1	$1	$1	$1	$2	$2	$3	$4
Total Cost to Dealer -- Long Term	$30	$31	$37	$39	$44	$64	$69	$96
Dealer Carrying Cost -- Long Term	$1	$1	$1	$1	$1	$2	$2	$3
Cost to Buyer w/ Nonroad Learning -- Long Term	$25	$26	$31	$32	$37	$53	$57	$79

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 6.2-21. Note that these costs will be incurred only by turbocharged engines.

Table 6.2-21
CCV Costs as a Function of
Engine Displacement (x represents engine displacement in liters)
$2002

Near-term Cost Function	$2(x) + $34	R^2=1
Long-term Cost Function	$2(x) + $24	R^2=1

6.2.2.6 Variable Costs of Conventional Technologies for Engines under 75 hp and over 750 hp

For the smaller engines, we have projected a different technology mix for complying with the applicable emission standards. As explained in Chapter 4 of the RIA, we are projecting that engines will comply either by adding a DOC or by making some engine modifications resulting in engine-out emission reductions to comply with the 2008 PM standards. For our cost analysis, we have assumed that all engines will add a DOC. Manufacturers will presumably choose the least costly approach that provides the necessary emission control. If engine-out modifications are less costly than a DOC, the analysis overestimates the costs associated with meeting these standards. If the DOC proves to be less costly, then our estimate is representative of what most manufacturers presumably will do. Therefore, we have assumed that, beginning in 2008, all engines under 75 hp will add a DOC. Note that, as discussed in Chapter 4, some engines under 75 hp already meet the new PM standards (i.e., such engines will not have to make any changes nor incur any incremental hardware costs for 2008), which also contributes to the likely overestimate of costs. Our cost estimates for DOCs are presented above in Section 6.2.2.4.

As discussed in Chapter 4, we have also projected that some engines in the 25 to 75 hp range will 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-injection (IDI) engines in this power range, we believe manufacturers will 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 hp range, we believe all engines will add cooled EGR to meet NOx standards. For our cost analysis, this is also true for engines over 750 hp. Note that engines over 750 hp are also assumed to add the previously discussed emission-control technologies, i.e., a CDPF system and some sort of CDPF regeneration system.

We project that manufacturers will add CCV systems to all these engines that are turbocharged, both large and small. The costs for CCV systems are presented in Section 6.2.2.5.

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.[36] Table 6.2-22 presents the costs to manufacturers as estimated by ICF for fuel-injection systems.

Table 6.2-22
Fuel-Injection System – Costs to Manufacturers

	Fuel System Costs ($2002)					
	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 hp range (represented in Table 6.2-22 by the 80 hp engine) are assumed to have electronic rotary fuel-injection systems as a baseline configuration while smaller engines are assumed to have mechanical fuel injection (see section II.A of the preamble and section 4.1 of the RIA for more discussion on why this is a valid assumption). 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 explains the large difference in fuel system costs for the 80 hp engine relative to the 20 and 35 hp engines.

The costs shown in Table 6.2-22 show consistency for all elements across the power 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 6.2-23, which also builds on the manufacturer costs shown in Table 6.2-22 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 this way to make possible a cost equation that applies 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 6.2-23
Incremental Fuel System Costs – Costs to the User

EPA Estimated Incremental Fuel System Costs for DI Engines ($2002)						
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	$65	$551	$65	$551	$56	$152
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	$75	$617	$75	$617	$65	$173
Dealer Carrying Cost (3%) -- Near Term	$2	$19	$2	$19	$2	$5
Total Cost to Buyer -- Near Term	$78	$636	$78	$636	$67	$178
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	$70	$588	$70	$588	$60	$163
Dealer Carrying Cost (3%) -- Long Term	$2	$18	$2	$18	$2	$5
Subtotal	$72	$605	$72	$605	$62	$168
Total Cost to Buyer -- Long-Term w/ learning	$58	$484	$58	$484	$50	$134

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 hp DI engines. Note also that, in determining aggregate variable costs for fuel-injection systems, we have attributed half of the costs to the 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 to 75 hp range will already be equipped with electronic fuel systems independent of this rule. This is due to the natural progression of electronic fuel systems currently available in larger power engines into some of the smaller power engines. In fact, recent certification data prove that this is already happening, as discussed in section 4.1.4 of this RIA. During our discussions with some engine companies, they have indicated that they intend to use electronic fuel system technologies to comply with the existing Tier 3 standards in the 50 to 100 hp range. These manufacturers have informed us that these electronic fuel systems will also be sold on engines in the 25 to 50 hp range for those engine product lines built on the same platform as engines over 50 hp. In addition, there are end-user benefits associated with electronic fuel systems, such as better torque response, lower noise, easier servicing via on-board diagnostics, and better engine startability. 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.[37] The incremental manufacturer costs for cooled EGR systems are shown in Table 6.2-24.

Table 6.2-24
Cooled EGR System – Costs to Manufacturers

ICF Estimated Cooled EGR System Costs to Manufacturers ($2002)			
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	$66	$95	$413

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 6.2-25. Included in these costs are costs associated with additional cooling that may be needed to reject the heat generated by the cooled EGR system or other in-cylinder technologies. These costs were not included in the proposal. Such additional cooling might take the form of a larger radiator and/or a larger or more powerful cooling fan. Based on cost estimates from our Nonconformance Penalty rule (67 FR 51464). In the support document for the NCP rule,[38] we estimated the costs associated with such additional cooling at $130 for a light heavy-duty vehicle (~200hp) and $300 for a heavy heavy-duty vehicle (~500hp), inclusive of *vehicle* manufacturer mark ups. Here, we have used these values to generate a curve with horsepower as the dependent variable. That curve is $0.60 + $16.7(x), with an R^2=1 and where “x” represents horsepower. Using this curve and the horsepowers shown in Table 6.2-25 we were able to estimate the costs for additional cooling. The results shown in Table 6.2-25 include a three percent dealer carrying cost.

Table 6.2-25
Cooled EGR System – Costs to the User

EPA Estimated Cooled EGR Costs ($2002)			
Horsepower	20	35	1000
Displacement (L)	1	2	24
EGR System Cost to Manufacturer	$66	$95	$413
Warranty Cost -- Near Term (3% claim rate)	$8	$10	$34
Mfr. Carrying Cost (4%) -- Near Term	$3	$4	$17
Total Cost to Dealer -- Near Term	$77	$109	$463
Dealer Carrying Cost (3%) -- Near Term	$2	$3	$14
EGR System Cost to Buyer -- Near Term	$79	$112	$477
Warranty Cost -- Long Term (1% claim rate)	$3	$3	$11
Mfr. Carrying Cost (4%)-- Long Term	$3	$4	$17
Total Cost to Dealer -- Long Term	$71	$102	$441
Dealer Carrying Cost (3%) -- Long Term	$2	$3	$13
Subtotal	$73	$105	$454
EGR System Cost to Buyer -- Long Term w/ learning	$59	$84	$363
Heat rejection cost to Buyer (incl 3% dealer carrying cost) – Near Term	$29	$38	$610
Heat rejection cost to Buyer (incl 3% dealer carrying cost) – Long Term	$23	$31	$488
Total EGR-related Costs to Buyer -- Near-term	$108	$151	$1,087
Total EGR-related Costs to Buyer -- Long-term	$82	$115	$851

Despite the presence of cost data for a 20hp engine in Table 6.2-25, we are projecting that only engines in the 25 to 50 hp range (in 2013) and engines over 750 hp will need to add cooled EGR (in 2011), or use some other equally effective approach having presumably similar costs, to comply with the new engine standards. All the costs associated with these systems have been attributed to compliance with the new emission 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 (inclusive of additional cooling). 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 6.2-26.

Table 6.2-26
Costs for Conventional Technologies as a
Function of the Indicated Parameter (x represents the dependent variable)
\$2002

Technology	Applicable Hp Range	Dependent Variable	Equation	R^2
Fuel System Costs – DI Only				
Near Term	25≤hp<50	# of cylinders	\$78(x) + \$636	—[a]
Long Term	25≤hp<50		\$58(x) + \$484	
Near Term	50≤hp<75		\$67(x) + \$178	—[a]
Long Term	50≤hp<75		\$50(x) + \$134	
Cooled EGR System (inclusive of additional cooling)				
Near Term	25≤hp<50; >750hp	displacement	\$43(x) + \$65	1
Long Term	25≤hp<50; >750hp		\$33(x) + \$48	1

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

6.2.2.7 Summary of Engine Variable Cost Equations

Engine variable costs are discussed in detail in Sections 6.2.2.1 through 6.2.2.6. 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 6.2-27. Note that not all equations were used for all engines; equations were used in the manner shown in Table 6.2-27. We have calculated the aggregate engine variable costs and present them later in this chapter and in Chapter 8.

Table 6.2-27
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	$103(x) + $183 $83(x) + $160	Displacement[b]	>75 hp engines according to phase-in of NRT4 NOx std.
CDPF System	Near term Long term	$146(x) + $75 $112(x) + $57	Displacement	>25 hp engines according to NRT4 PM std.
CDPF Regen System – IDI engines	Near term Long term	$20(x) + $293 $16(x) + $223	Displacement	IDI engines adding a CDPF
CDPF Regen System – DI engines	Near term Long term	$10(x) + $147 $8(x) + $111	Displacement	DI engines adding a CDPF
DOC	Near term Long term	$18(x) + $116 $18(x) + $110	Displacement	<25 hp engines beginning in 2008; 25-75 hp engines 2008 thru 2012
CCV System	Near term Long term	$2(x) + $34 $2(x) + $24	Displacement	All turbocharged engines when they first meet a Tier 4 PM std.
Cooled EGR System w/ additional cooling	Near term Long term	$43(x) + $65 $33(x) + $48	Displacement	25-50 hp engines beginning in 2013; >750hp engines beginning in 2011
Common Rail Fuel Injection (mechanical fuel system baseline)	Near term Long term	$78(x) + $636 $58(x) + $484	# 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	$67(x) + $178 $50(x) + $134	# of cylinders/ injectors	50-75 hp DI engines when they add a CDPF

[a] Near term = years 1 and 2; Long term = years 3+. Explanation of near term and long term is in Section 6.1.
[b] Displacement refers to engine displacement in liters.

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 Tier 4 emission 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. The incremental cost for low-sulfur fuel is described in Chapter 7 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 we present these lifetime operating costs as a net present value (NPV) in 2002 dollars for several example pieces of equipment.

A note of clarification needs to be added here. In Chapter 8 we present aggregate operating costs. Every effort is made to be clear what costs are related to (1) the incremental increase in the cost of fuel (due to the lower sulfur level), and (2) what costs are related to the expected change in maintenance demands and the expected change in fuel consumption. The operating costs discussed in this section are only the latter—maintenance related costs and/or savings and fuel consumption costs. Increased costs associated with the lowering of sulfur in nonroad diesel fuel are discussed in detail in Chapter 7. The cent-per-gallon costs presented in Chapter 7, along with the cent-per-gallon costs and savings presented here, are then combined with projected fuel volumes to generate the aggregate costs of the fuel program in this final rule.

Total operating costs 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 (extended oil change intervals results in maintenance savings); the change in fuel costs associated with the incrementally higher costs for low-sulfur fuel (see Chapter 7), 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 increase in fuel consumption, 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 is far less corrosive than current nonroad diesel fuel. Less corrosion corresponds with a slower acidification rate (i.e., less degradation) of the engine lubricating oil and therefore more operating hours between 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 will reduce engine wear and oil degradation to the existing fleet of nonroad diesel engines, as well as locomotive and marine diesel engines. Reducing fuel sulfur to 15 ppm will further reduce engine wear and oil degradation. These improvements provide a savings to users of this equipment. The cost savings will also be realized by the owners of future nonroad engines that are subject to the emission standards in this final rule. As discussed below, these maintenance savings have been estimated to be greater than 3 cents/gallon when comparing current uncontrolled fuel to 15 ppm sulfur fuel.

We have identified a variety of benefits from the low-sulfur diesel fuel. These benefits are summarized in Table 6.2-28.

Table 6.2-28.
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 will be substantial. Additional savings will be realized in 2010 with the introduction of 15 ppm sulfur fuel.

We estimate the single largest savings will be the impact of lower sulfur fuel on oil-change intervals. We have estimated the extension of oil-change intervals realized by 500 ppm sulfur fuel in 2007 and the additional extension resulting from 15 ppm sulfur 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 levels that nonroad engines may currently 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 with the relatively high sulfur levels in current nonroad diesel fuel, we estimate the use of 500 ppm sulfur fuel will enable an oil-change interval extension of 31 percent, while 15 ppm sulfur fuel will enable an oil-change interval extension of 35 percent relative to current products.[39]

We present here a fuel cost savings attributed to the oil-change interval extension in terms of a cent-per-gallon operating cost. Table 6.2-29 shows the calculation of cent-per-gallon savings for various power segments of the nonroad fleet, and the locomotive and marine segments, for both the 500 ppm fuel and the 15 ppm fuel. The brake specific fuel consumption (BSFC), average hp, average activity, and average load factor data shown in the table are from our nonroad model.[40] The existing and new NRLM fleets will 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. We estimate that an oil-change interval extension of 31 percent enabled by 500 ppm sulfur fuel results in a weighted savings in fuel operating costs of 2.9 cents/gallon for the nonroad fleet. We project an additional weighted cost savings of 0.3 cents/gallon for the oil-change interval extension enabled by 15 ppm sulfur. Note that the weighted savings are determined using the fuel use weightings shown in Table 6.2-29. For locomotive and marine engines, these savings are 1 cent/gallon and 0.1 cent/gallon for the 500 ppm step and the 15 ppm step, respectively.

Thus, for the nonroad fleet as a whole, beginning in 2010, nonroad equipment users can realize an operating cost savings of 3.2 cents/gallon relative to current engines. For a typical 100 hp nonroad engine, this represents a net present value lifetime savings of more than $500. For locomotive and marine engines the savings are estimated at 1.1 cents/gallon, which represents a net present value lifetime savings of more than $2000.

Table 6.2-29. Oil-Change Maintenance Savings for Existing and New Nonroad, Locomotive, and Marine Engines ($2002)

Oil Change Savings due to Low S	Units	Nonroad Engines								Locomotive	Marine
Rated Power	hp	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<175	175<=hp<300	300<=hp<600	600<=hp<750	>750hp		
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.390	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	16	37	60	109	234	413	694	1282	1282	1282
Population Weighted Avg. Activity	hrs/year	523	582	764	675	537	619	947	1130	1130	1130
Population Weighted avg. Load Factor	% full load	0.41	0.44	0.40	0.47	0.57	0.57	0.56	0.57	0.57	0.57
Sump Oil Capacity	L	1.58	3.62	5.83	10.55	22.68	40.07	67.33	124.32	124.32	124.32
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	$	$3.16	$7.25	$11.65	$21.11	$45.35	$80.13	$134.66	$248.65	$248.65	$248.65
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	$	$71.16	$75.25	$79.65	$89.11	$130.35	$165.13	$219.66	$418.65	$418.65	$418.65
Fuel Consumption in 3000 ppm Oil Interval	gallons	96	237	349	699	1732	3043	5044	9463	9463	9463
Fuel Consumption in 500 ppm Oil Interval	gallons	125	310	457	916	2269	3986	6608	12396	12396	12396
Oil Change Cost/Gallon fuel in 3000 ppm Interval	$/gallon	$0.74	$0.32	$0.23	$0.13	$0.08	$0.05	$0.04	$0.04	$0.04	$0.04
Oil Change Cost/Gallon fuel 500 ppm Interval	$/gallon	$0.57	$0.24	$0.17	$0.10	$0.06	$0.04	$0.03	$0.03	$0.03	$0.03
Cost Differential -- 3000 to 500 ppm S	$/gallon	$0.176	$0.075	$0.054	$0.030	$0.018	$0.013	$0.010	$0.010	$0.010	$0.010
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	$	$3.16	$7.25	$11.65	$21.11	$45.35	$80.13	$134.66	$248.65	$248.65	$248.65
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	$	$71.16	$75.25	$79.65	$89.11	$130.35	$165.13	$219.66	$418.65	$418.65	$418.65
Fuel Consumption in 500 ppm Oil Interval	gallons	125	310	457	916	2269	3986	6608	12396	12396	12396
Fuel Consumption in 15 ppm Oil Interval	gallons	129	320	471	944	2338	4108	6809	12774	12774	12774
Oil Change Cost/Gallon fuel in 500 ppm Interval	$/gallon	$0.57	$0.24	$0.17	$0.10	$0.06	$0.04	$0.03	$0.03	$0.03	$0.03
Oil Change Cost/Gallon fuel in 15 ppm Interval	$/gallon	$0.55	$0.24	$0.17	$0.09	$0.06	$0.04	$0.03	$0.03	$0.03	$0.03
Cost Differential -- 500 to 15 ppm S	$/gallon	$0.017	$0.007	$0.005	$0.003	$0.002	$0.001	$0.001	$0.001	$0.001	$0.001
Cost Differential -- 3000 to 15 ppm S	$/gallon	$0.193	$0.082	$0.059	$0.033	$0.020	$0.014	$0.011	$0.011	$0.011	$0.011
Fuel Use Weightings	% total	1.8%	5.2%	9.2%	31.6%	23.1%	18.8%	4.1%	6.2%		

(1) Oil-change intervals are from William Charmley memo to docket.[41]

(2) Labor costs are from ICF Consulting under contract to EPA.[42]

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

The savings shown in Table 6.2-29 will 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 potential savings. We have not estimated the value of the savings from the other benefits listed in Table 6.2-28. Therefore, we believe the 3.2 cents/gallon savings underestimates actual cost savings as it accounts only for the impact of low-sulfur fuel on oil-change intervals.

Operating costs (savings) associated with oil-change maintenance are split 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 are discussed in Section 4.1.1.3.4. To avoid underestimating costs, we have used a maintenance interval of 3,000 hours for engines under 175 hp and 4,500 hours for engines over 175 hp, 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 hp and $260 per event for engines over 600 hp. The calculations for CDPF maintenance are shown in Table 6.2-30. Weighting the savings in each power range by the fuel-use weightings shown in the table, we can calculate the fleet weighted maintenance costs as 0.6 cents/gallon, which will be incurred only by new engines equipped with a CDPF. Operating costs associated with CDPF maintenance are attributed entirely to PM control.

Table 6.2-30
CDPF Maintenance Costs for New CDPF-Equipped Engines ($2002)

PM Filter Maintenance Costs	Units	Nonroad Engines							
Rated Power	hp	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<175	175<=hp<300	300<=hp<600	600<=hp<750	>750hp
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.390	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	16	37	60	109	234	413	694	1282
Population Weighted Avg. Activity	hrs/year	523	582	764	675	537	619	947	1130
Population Weighted avg. Load Factor	% full load	0.409	0.441	0.404	0.468	0.573	0.570	0.562	0.571
Filter Maintenance Interval	hours		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
Filter Maintenance Labor	$/event		$65	$65	$65	$65	$65	$130	$260
Total Filter Maintenance Cost per event	$/event		$65	$65	$65	$65	$65	$130	$260
Fuel Use Between Maintenance Interval	gallons/period		2,844	4,185	8,391	31,174	54,767	90,791	170,326
Maintenance Cost	$/gallon		$0.023	$0.016	$0.008	$0.002	$0.001	$0.001	$0.002
Fuel Use Weightings	% total	1.8%	5.2%	9.2%	31.6%	23.1%	18.8%	4.1%	6.2%

Labor costs are from ICF Consulting under contract to EPA.[43]

6.2.3.3 Operating Costs Associated with Fuel Economy Impacts on New Engines

6.2.3.3.1 What Are the Estimated Fuel Economy Impacts?

The high efficiency emission-control technologies expected to be applied to meet the PM standards for engines greater than 25 hp and the NOx standards for engines greater than 75 hp 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 the integration of the engine and exhaust emission-control systems into a single synergistic emission-control system will lead to nonroad engines that can meet demanding emission-control targets with only a small impact on fuel consumption. Technology improvements have historically eliminated these marginal impacts in the past and it is our expectation that this kind of continuing improvement will eliminate the modest impact estimated here. However, because we cannot project the time frame for this improvement to be realized, we have included this impact in our cost estimates for the full period of the program to avoid underestimating costs.

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.[P] This approach results in filtering efficiencies for diesel PM greater than 90 percent but requires additional pumping work to force the exhaust through these small openings. The impact of this additional pumping work on fuel consumption is dependent on engine operating conditions. At low exhaust flow conditions (i.e., low engine load, low turbocharger boost levels), the impact is so small that it typically cannot be measured, while at very high load conditions, with high exhaust flow conditions, the fuel economy impact can be as large as one to two percent.[44,45] We have estimated that the average impact of this increased pumping work will be equivalent to an increase fuel consumption of approximately one percent.[46]

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 several typical in-use operating cycles, as described in Section 4.1.3. 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. We believe some manufacturers will address this situation by employing active backup regeneration systems that

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[P] Typically, the filtering media is a porous ceramic monolith or a metallic fiber mesh. We refer to it as a “filter trap” in Table 6.2-13.

provide supplemental heat to initiate regeneration, as discussed in Section 4.1. Also, as explained in Section 6.2.2.3, we are conservatively costing active regeneration systems for all engines using a CDPF system. We have done this because we think 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 experience passive regeneration in use. Examples of current active PM filter systems 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.[47] Given the new requirements for clean diesel fuel in this final rule, the ability to use catalytic coatings to promote soot oxidation, and the fact that many kinds of nonroad equipment are expected to operate in a way that passive regeneration will occur, we believe the average fuel economy impact of the backup regeneration systems will be no more than one percent.

We have projected that engines between 25 hp to 75 hp 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 power 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. We therefore 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 occur for engines between 25 hp and 75 hp. We believe manufacturers will overcome this impact in the long term through continuing technology refinement, as has historically happened. However, to avoid underestimating costs, we have included this two percent impact for the duration of the program.

For engines under 25 hp we have projected no need to use CDPF technologies to comply with the PM standards in the final rule. We therefore estimate no fuel consumption impact from the CDPF for this category.

We believe engines all engines between 75 hp and 750 hp and mobile gensets above 750hp will use integrated NOx and PM control technologies to comply with the new emission standards. The advanced catalyst-based emission-control technology that we project industry will use to meet the new NOx standard offers the opportunity to improve fuel economy, as described in the following section. Based on those projected improvements, we have estimated a net impact on fuel consumption of one percent for engines between 75 and 750 hp as well as gensets >750 hp with CDPF technology and NOx technology. Future technology improvements are likely to recover this fuel consumption impact; however, to avoid underestimating costs, we have assumed that a one-percent fuel consumption impact persists for the duration of the emission-control program.

At this time we are not setting a NOx standard for nonroad mobile machine engines >750 hp based on the use of advanced NOx catalyst based technologies (see Preamble Section II.A). These engines, like the smaller engines between 25 and 75 hp, are projected to use diesel particulate filter technologies to meet the Tier 4 PM standards. Therefore like the 25 to 75 hp engines, we are estimating that nonroad mobile machines above 750 hp will have a two percent fuel economy impact (i.e., one percent due to backpressure and one percent due to use of backup regeneration systems). We believe manufacturers will overcome this impact in the long term through continuing technology refinement, as has historically happened. However, to avoid underestimating costs, we have included this two percent impact for the duration of the program.

6.2.3.3.1.2 NOx Control and Fuel Economy

NOx adsorbers are expected to be the primary technology to reduce NOx emissions for engines between 75 and 750 hp as well as for mobile gensets above 750 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. 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 highway diesel engines, can be made to operate in this way, it is anticipated that fuel economy during operation under these conditions will be worse than normal. This increase in fuel consumption can be minimized by carefully controlling engine air-fuel ratios using the control systems we anticipate will be used to meet the Tier 3 emission standards. The lower the engine air-fuel ratio, the lower the amount of fuel that must be added to reach rich conditions. In the ideal case where the engine air-fuel ratio is at the stoichiometric level and additional fuel is required only as a NOx reductant, the fuel economy penalty is nearly zero. We are projecting that practical limitations on controlling engine air-fuel ratio will mean that the NOx adsorber release and reduction cycles will lead to a one percent decrease in the engine fuel economy.[48] 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, sulfur affects NOx adsorbers even at the low fuel-sulfur levels we are adopting. As discussed in Chapter 4, this effect 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.[49] 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 both highway and nonroad diesel engines. With a 15 ppm fuel sulfur cap, we are projecting that fuel consumption for desulfation will 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 impact fuel economy by requiring nonpower-producing fuel consumption to function properly, they are not unique among NOx control technologies in this way. In fact, NOx adsorbers are likely to have a very favorable tradeoff between NOx emissions and fuel economy compared with our projected technologies for meeting Tier 3 NOx standards—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.[50]

Nonroad diesel engines generally rely primarily on charge-air-cooling and injection timing control (retarding injection timing) to meet Tier 2 NOx+NMHC emission standards. 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 compared with timing control, we forecast that less reliance on timing control will be needed for Tier 3 than for Tier 2. Fuel economy will therefore not change even at this lower NOx level. Similarly for the 25-50 hp engines subject to a Tier 4 NOx standard of 3.3 g/hp-hr, we believe the NOx standard will not cause a change in fuel consumption. NOx adsorbers have a significantly more favorable trade-off between NOx emissions and fuel economy compared with cooled EGR or timing retard.[51] 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.[Q] We therefore 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 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

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[Q] We have 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 estimating the total consumption to be approximately 2.5 percent of total fuel consumption. Additionally the contractor's estimate of NOx adsorber efficiency ranges from 80 to 90 percent, while we believe over 90 percent control is possible, as discussed in Chapter 4.

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 with current technologies. This will result in 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 between 75 and 750 hp as well as mobile gensets above 750 hp.

6.2.3.3.1.3 Fuel Economy Impacts for Engines without Advanced Emission-Control Technologies (engines under 25 hp)

The new NOx emission standard for engines under 25 hp is unchanged from the current Tier 2 level. The PM standard, however, decreases by almost 50 percent. We believe manufacturers will achieve this significant PM reduction 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 can 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 may 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. We therefore estimate no change in fuel consumption in our cost analyses for engines under 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/gallon. To that, we have added the incremental cost per gallon for 15 ppm fuel. These incremental fuel costs are discussed in Chapter 7 as 7.0 cents/gallon. Using this 67 cent value, we apply the estimated fuel economy impact of an engine – 1% where both a CDPF and a NOx adsorber are added, and 2% where a CDPF is added and no NOx adsorber is present. This results in an increased operating cost for 75-750 hp engines of 0.67 cents/gallon (1% × 67 cents/gallon) for CDPF/NOx adsorber equipped engines and 1.34 cents/gallon for CDPF-only engines (2% × 67 cents/gallon). For 25-75 hp engines, and for >750 hp engines, where we estimate a two percent fuel economy impact, the estimated incremental cost is 1.34 cents/gallon. Importantly, these fuel economy impacts are incurred only on new engines; existing engines that do not meet the NRT4 standards will not see any fuel economy impact.

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 is shown in Table 6.2-31. The new CCV requirements apply only to turbocharged engines (naturally aspirated engines already have a closed crankcase requirement) so there are two cent/gallon values shown in Table 6.2-31 within each power range. The first value is the cent/gallon cost for a turbocharged engine while the weighted cent/gallon cost within the power range (i.e., weighted by the percentage of turbocharged engines). Using the fuel use weightings, we can calculate the fleetwide cent/gallon cost using these latter costs within each power range. The result is a 0.2 cent/gallon cost.

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

Table 6.2-31
Closed Crankcase Ventilation System
Maintenance Costs for New Turbocharged Engines ($2002)

CCV Maintenance Costs	Units	Nonroad Engines							
Rated Power	hp	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<175	175<=hp<300	300<=hp<600	600<=hp<750	>750hp
BSFC	lbm/hp-hr	0.408	0.408	0.408	0.390	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	16	37	60	109	234	413	694	1282
Population Weighted Avg. Activity	hrs/year	523	582	764	675	537	619	947	1130
Population Weighted avg. Load Factor	% full load	0.409	0.441	0.404	0.468	0.573	0.570	0.562	0.571
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	259	640	942	1,888	4,676	8,215	13,619	25,549
Turbcharged Fleet Fraction	[%]	0%	2%	9%	62%	99%	100%	100%	100%
Maintenance Cost for engines adding CCV	$/gallon	$0.031	$0.013	$0.008	$0.004	$0.002	$0.001	$0.002	$0.002
Maintenance Cost - weighted for all engines	$/gallon	$0.000	$0.000	$0.001	$0.003	$0.002	$0.001	$0.002	$0.002
Fuel Use Weightings	% total	1.8%	5.2%	9.2%	31.6%	23.1%	18.8%	4.1%	6.2%

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,[52] 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 transition program for equipment manufacturers is to reduce the potential for anomalously high costs for individual equipment models by providing significant additional time (up to seven years) for developing less costly designs or to align the changes with an already scheduled redesign. To remain conservative in our cost estimates, we have not factored into the analysis the significant potential cost savings associated with these provisions; Section 6.3.3 explores the potential cost savings of the transition program for equipment manufacturers.

6.3.1 Equipment Fixed Costs

6.3.1.1 Equipment Redesign Costs

The projected modifications to equipment resulting from the new emission standards relate to the need to package emission-control hardware that engine manufacturers will incorporate into their engines. As noted in Section 6.2, the additional emission-control hardware is proportional in size to engine displacement by a 4:1 ratio (1.5 × engine displacement for both the CDPF and the NOx adsorber, and 1.0 × 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. Some redesigns will be major in scale, while others will be minor. For example, redesign may simply involve bolting the new devices onto the existing design, but in most cases we expect devices to be designed into the piece of equipment in a way that their presence would not be obvious to the casual observer and, in fact, for some equipment they may simply replace the existing muffler with no redesign needed. Additionally, a redesign to accommodate a DOC (1.0 × engine displacement) should be less intensive than a redesign to accommodate a CDPF/NOx adsorber system. Finally, for engines in the 75-750 hp range where the final rule phases in new NOx standards, we assume that the redesign effort for those final pieces of complying equipment (i.e., when the phase-in goes from 50 percent to 100 percent) will be less costly than the first redesign effort.

6.3.1.1.1 Schedule of Equipment Redesigns

The final rule includes a varying compliance dates for different engines, as shown in Table 6.3-1. For this analysis, because we are assuming no use of the transition program for equipment manufacturers, we assume that the timing of equipment redesigns will correlate with the timing of new emission standards (assuming no use banking under the engine ABT program). This results in a redesign schedule as shown in Table 6.3-1. We have noted the percentage of equipment models we estimate will be redesigned in years for which new emission standards are implemented. The table also notes the estimated percentage that will be major or minor redesign efforts. We also note what percentage of the redesign costs are allocated to PM and to NOx.

Table 6.3-1
Equipment Redesign Assumptions for Equipment Manufacturers

Power	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%	
>750 hp	2011	100% NOx	100%	
	2015	100% PM		100%

Note that we have assumed all equipment redesigns for the 75 to 750 hp range are major in the first year of new emission 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 believe this is appropriate because equipment manufacturers will expend less effort to redesign those pieces equipment needing to add only the NOx adsorber (in those years where the NOx phase-in schedule changes from 50 percent to 100 percent) for three reasons: (1) these models will already have been redesigned for the CDPF system and will already incorporate the necessary electronic systems into their design; (2) equipment manufacturers will presumably have gained experience during the major redesign phase that should make the minor redesign phase more efficient; and (3) manufacturers that are 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.

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 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/Tier 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 increases heat rejection and requires 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 (for example, 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 engines still without electronic fuel systems will require them, and equipment manufacturers will need to integrate aftertreatment systems (as compared with charge-air-coolers, turbochargers, larger radiators and fans). However, we believe that equipment redesigns attributable to Tier 4 are more likely to occur early in the design cycle than many design changes attributable to the Tier 2/3 rules.

Some companies we met with before the proposal gave us 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). We also received redesign cost estimates from several equipment manufacturers during the Tier2/3 rulemaking regarding their projected costs for the Tier 2 standards (these data are confidential business information). The information provided to us 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, we learned that 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 judgment, to develop the redesign cost estimates presented in Table 6.3-2. This table presents fixed cost per motive and nonmotive equipment model (motive equipment is that with some form of propulsion system while nonmotive equipment, such as air compressors, generator sets, hydraulic power units, irrigation sets, pumps, compressors, and welders, has none) for each power group. In general, nonmotive 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 nonmotive equipment relative to motive equipment.

Table 6.3-2
Estimated Equipment Redesign Costs Per Model
($2002)

Power	Motive	Nonmotive
0<hp<25	$53,100	$53,100
25≤hp<75		
2008	$53,100	$53,100
2013	$199,125	$79,650
75≤hp<100	$371,700	$106,200
100≤hp<175	$531,000	$106,200
175≤hp<300	$531,000	$106,200
300≤hp<600	$796,500	$106,200
600≤hp≤750	$796,500	N/A
>750hp		
2011	$106,200	N/A
2015	$796,500	N/A

Using the PSR database we were able to determine the number of equipment models and the type of equipment model (motive versus nonmotive). We distinguished motive from nonmotive using our Nonroad Model definition of stationary applications. Nonmotive applications include air compressors, generator sets, pumps, hydraulic power units, irrigation sets, and welders. All other applications are considered motive. Table 6.3-3 shows the number of equipment models we have estimated to be redesigned. Note that the models shown in Table 6.3-3 are not necessarily all models but are instead the unique models that had 2000 model year sales. The determination of unique models was based on manufacturer name (i.e., a Caterpillar skid/steer loader is unique from a Bobcat skid/steer loader) and the market segment to which the model belonged (i.e., an agricultural tractor is unique from a construction backhoe) and the engine displacement. Therefore, while a manufacturer may consider two pieces of construction equipment with the same base engine, one with and one without a turbocharger, to be two distinct models, we consider that one model for the sake of equipment redesign.

Table 6.3-3
Number of Motive vs. Nonmotive Equipment Models
to be Redesigned

Power Range	Motive	Nonmotive	Total
0<hp<25	245	268	513
25≤hp<50	407	177	584
50≤hp<75	277	146	423
75≤hp<100	354	153	507
100≤hp<175	662	244	906
175≤hp<300	648	241	889
300≤hp<600	386	188	574
600≤hp≤750	80	0	80
<750hp	86	0	86
Total	3,145	1,417	4,563

Equipment redesign costs are estimated to occur during the two year period prior to the start of the new emission standards for which the redesign is done. As done for engine fixed costs, we have attributed only a portion of the equipment redesign costs to sales within the United States. This is appropriate because we believe these efforts will be needed to sell equipment not only in the United States, but also in Australia, Canada, Japan, and the countries of the European Union. As discussed in Section 6.2.1.1, we have therefore attributed 42 percent of the equipment fixed costs to U.S. sales. This is true with the exception of the <25hp range where we do not expect other countries to have standards as low as the NRT4 standards and, as a result, all redesign costs in this power range are attributed to today's rule. Table 6.3-4 shows the total redesign cost expenditures attributable to US sales for each power range.

Table 6.3-4

Equipment Redesign Expenditures Attributable to US Sales ($2002)

Year Incurred	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
2006	$ 6,810,075	$ 7,752,600	$ 5,615,325							$ 20,178,000
2007	$ 6,810,075	$ 7,752,600	$ 5,615,325							$ 20,178,000
2008										$ -
2009						$ 184,841,100	$ 163,707,300	$ 31,860,000	$ 4,566,600	$ 384,975,000
2010				$ 73,915,200	$ 188,717,400	$ 184,841,100	$ 163,707,300	$ 31,860,000	$ 4,566,600	$ 647,607,600
2011		$ 47,570,963	$ 33,393,263	$ 73,915,200	$ 188,717,400					$ 343,596,825
2012		$ 47,570,963	$ 33,393,263	$ 18,478,800	$ 47,179,350	$ 46,210,275	$ 40,926,825	$ 7,965,000		$ 241,724,475
2013				$ 18,478,800	$ 47,179,350	$ 46,210,275	$ 40,926,825	$ 7,965,000	$ 34,249,500	$ 195,009,750
2014									$ 34,249,500	$ 34,249,500
Total to US Sales	$ 13,620,150	$ 46,471,793	$ 32,767,214	$ 77,610,960	$ 198,153,270	$ 194,083,155	$ 171,892,665	$ 33,453,000	$ 32,605,524	$ 800,657,730

Table 6.3-5

Expenditures for Changes to Product Support Literature Attributable to US Sales ($2002)

Year Incurred	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
2006	$ 1,006,245	$ 2,631,105	$ 1,858,500							$ 5,495,850
2007	$ 1,006,245	$ 2,631,105	$ 1,858,500							$ 5,495,850
2008										$ -
2009						$ 4,080,735	$ 2,548,800	$ 424,800	$ 228,330	$ 7,282,665
2010				$ 2,285,955	$ 4,163,040	$ 4,080,735	$ 2,548,800	$ 424,800	$ 228,330	$ 13,731,660
2011		$ 2,631,105	$ 1,858,500	$ 2,285,955	$ 4,163,040					$ 10,938,600
2012		$ 2,631,105	$ 1,858,500	$ 1,142,978	$ 2,081,520	$ 2,040,368	$ 1,274,400	$ 212,400		$ 11,241,270
2013				$ 1,142,978	$ 2,081,520	$ 2,040,368	$ 1,274,400	$ 212,400	$ 456,660	$ 7,208,325
2014									$ 456,660	$ 456,660
Total to US Sales	$ 2,012,490	$ 4,420,256	$ 3,122,280	$ 2,880,303	$ 5,245,430	$ 5,141,726	$ 3,211,488	$ 535,248	$ 575,392	$ 27,144,614

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 will be about 100 hours—75 hours of junior engineering time, 20 hours of senior engineering time, and 5 hours of clerical time—which amounts to about $10,620 in $2002. We projected that the level of effort needed by equipment manufacturers to modify support literature for each nonmotive application product line will be about 50 hours (distributed similarly), which is equivalent to about $5,310. With the exception of the <25hp costs, we have attributed only a portion of the product support literature costs to US sales as described above for equipment redesign costs. Table 6.3-5 presents the total costs per power category for changes to support literature.

6.3.1.3 Total Equipment Fixed Costs

The annual equipment fixed costs for each power category are shown in Table 6.3-6. As described above and with the exception of <25 hp expenditures, we have attributed only a portion of the equipment fixed costs to sales within the United States. This is appropriate because we believe these efforts will be needed to sell equipment not only in the United States, but also in Australia, Canada, Japan, and the countries of the European Union. As discussed in Section 6.2.1.1, we have therefore attributed 42 percent of the equipment fixed costs to U.S. sales.

The analysis projects that the expenditures will be incurred over a two-year period before the first year of the emission standards. The costs were then amortized over ten years at a seven percent rate beginning with the first year of the engine standard. The ten-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.

Table 6.3-6
Recovered (Annualized) Equipment Fixed Costs per Power Category ($2002)

Year Recovered	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	$ 2,303,637	$ 1,285,326	$ 925,132	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,514,096
2009	$ 2,303,637	$ 1,285,326	$ 925,132	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,514,096
2010	$ 2,303,637	$ 1,285,326	$ 925,132	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,514,096
2011	$ 2,303,637	$ 1,285,326	$ 925,132	$ -	$ -	$ 23,385,312	$ 20,579,679	$ 3,996,309	$ 593,531	$ 53,068,927
2012	$ 2,303,637	$ 1,285,326	$ 925,132	$ 9,432,408	$ 23,875,320	$ 23,385,312	$ 20,579,679	$ 3,996,309	$ 593,531	$ 86,376,654
2013	$ 2,303,637	$ 7,499,489	$ 5,288,701	$ 9,432,408	$ 23,875,320	$ 23,385,312	$ 20,579,679	$ 3,996,309	$ 593,531	$ 96,954,385
2014	$ 2,303,637	$ 7,499,489	$ 5,288,701	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 593,531	$ 117,689,513
2015	$ 2,303,637	$ 7,499,489	$ 5,288,701	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 4,889,563	$ 121,985,546
2016	$ 2,303,637	$ 7,499,489	$ 5,288,701	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 4,889,563	$ 121,985,546
2017	$ 2,303,637	$ 7,499,489	$ 5,288,701	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 4,889,563	$ 121,985,546
2018	$ -	$ 6,214,163	$ 4,363,569	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 4,889,563	$ 117,471,450
2019	$ -	$ 6,214,163	$ 4,363,569	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 4,889,563	$ 117,471,450
2020	$ -	$ 6,214,163	$ 4,363,569	$ 11,861,250	$ 29,972,978	$ 29,357,921	$ 25,803,473	$ 5,008,533	$ 4,889,563	$ 117,471,450
2021	$ -	$ 6,214,163	$ 4,363,569	$ 11,861,250	$ 29,972,978	$ 5,972,609	$ 5,223,794	$ 1,012,223	$ 4,296,033	$ 68,916,619
2022	$ -	$ 6,214,163	$ 4,363,569	$ 2,428,843	$ 6,097,658	$ 5,972,609	$ 5,223,794	$ 1,012,223	$ 4,296,033	$ 35,608,892
2023	$ -	$ -	$ -	$ 2,428,843	$ 6,097,658	$ 5,972,609	$ 5,223,794	$ 1,012,223	$ 4,296,033	$ 25,031,160
2024	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 4,296,033	$ 4,296,033
Total	$ 23,036,370	$ 74,994,887	$ 52,887,014	$ 118,612,501	$ 299,729,780	$ 293,579,210	$ 258,034,732	$ 50,085,325	$ 48,895,635	$ 1,219,855,455

6.3.2 Equipment Variable Costs

In addition to the incrementally higher cost of new engines estimated in Sections 6.2.1 and 6.2.2, equipment manufacturers will 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 have 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 (shrouding) the new aftertreatment devices.

New brackets and bolts will be required to secure the aftertreatment devices within the piece of equipment. Additionally, increased labor ($29/hour) and overhead costs (40%) will be incurred to install these devices. Table 6.3-7 shows the costs we have used per piece of equipment ($/machine as shown in the table). Total costs per power range were calculated using these costs and equipment sales in the year 2000.

Table 6.3-7
Costs for Brackets and Bolts and Associated Labor for Equipment ($2002)

Brackets/bolts/etc.

	devices added	new sets of brackets/bolts per device	$/set	$/machine
0<hp<25	1	0	$2	$0
25<=hp<75				
2008	1	0	$0	$0
2013	1	2	$2	$4
75<=hp<175	2	2	$5	$21
175<=hp<300	2	2	$5	$21
300<=hp<=750	2	2	$11	$42
>750hp	2	2	$11	$42

Labor

	device added	hrs to install	subtotal ($)	overhead	Total
0<hp<25	DOC	0	$0	$0	$0
25<=hp<75					
2008	DOC	0	$0	$0	$0
2013	DPF	0.25	$7	$3	$10
75<=hp<175	DPF&NOxAds	0.5	$14	$6	$20
175<=hp<300	DPF&NOxAds	0.75	$22	$9	$30
300<=hp<=750	DPF&NOxAds	1.5	$43	$17	$61
>750hp	DPF	1	$29	$12	$40

Note to Table 6.3-7: We have assumed the addition of two devices for engines >750hp when only a CDPF is being added. It may have been more appropriate to assume one device but that the number of brackets and bolts needed would be twice that for other engines (i.e., four sets rather than two) given the size of the device. Applying two smaller CDPFs needing two sets of brackets and bolts leads to the same resultant cost for brackets and bolts.

Sheet metal costs vary by size of the aftertreatment devices being added which, in turn, vary by engine displacement as described in section 6.2. The amount of sheet 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 unique equipment model (as described in section 6.3.1.1.2) in the PSR database with an engine between 75 and 750 hp (1.5 times engine displacement for the CDPF and 1.5 times engine displacement for the 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 $1.14 per square foot for hot rolled steel. The sheet metal cost for each model was multiplied by the total sales for that model using the 2000 sales information in the 2002 PSR Sales Database.

Summing these variable costs for each equipment model—sheet metal costs plus costs for bolts, brackets, and labor—within each power range and then dividing by sales within the power range gives a rough estimate of the costs we have estimated for a piece of equipment. It is important to realize that this is weighted value within each power range determined by calculating a unique cost for each piece of equipment, multiplying that cost by its sales, and then totaling those costs within each power range. Table 6.3-8 shows the sales weighted equipment variable costs within each power range. A twenty-nine percent manufacturer markup is also included in the final cost estimates shown in Table 6.3-8.

Table 6.3-8
Sales Weighted Variable Costs per Piece of Equipment by Power Range[a]
Totals include a 29% Manufacturer Markup ($2002)

Power Range	Year	Total
0<hp<25	2008	$0
25≤hp<50	2013	$20
50≤hp<75	2013	$21
75≤hp<100	2012	$60
100≤hp<175	2012	$61
175≤hp<300	2011	$77
300≤hp<600	2011	$146
600≤hp≤750	2011	$154
>750 hp	2011	$123

[a] These costs do not include the engine variable costs described in section 6.2.

As shown in Table 6.3-8, we have estimated equipment variable costs to be zero for equipment with engines under 25 hp, under the expectation that an added DOC will replace the existing muffler and make use of the same bracket/bolt/labor used for the muffler. This is also expected for engines in the 25 to 75 hp range from 2008 through 2012 when, for our cost anlaysis, only a DOC is being used by the engine manufacturer for compliance; additional bolts and labor costs are included for the addition of a CDPF beginning in 2013.[R] 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.

[R] Note that for costing purposes we have assumed that a DOC is used on all engines under 75 hp to comply with the 2008 standards, although test data show that some engines already meet the new emission standards without a DOC.

6.3.3 Potential Impact of the Transition Provisions for Equipment Manufacturers

As discussed in Section III.B of the preamble, we are extending, and in some respects are expanding, the transition program for equipment manufacturers (TPEM) that was developed in the 1998 final rule. The TPEM is an important component of this final rule because of the flexibility it provides for equipment manufacturers. However, as explained earlier, because the program is optional, we have not included the potential impacts of TPEM on the estimated costs of the Tier 4 program. Nevertheless, this section discusses how the TPEM program may substantially reduce equipment manufacturer costs.

The TPEM can reduce equipment manufacturer costs in two ways. First, it allows equipment manufacturers to continue to sell limited numbers of equipment with non-Tier 4 engines even after the Tier 4 standards go into effect. Any engine price increase associated with the Tier 4 standards will therefore not be incurred by the equipment manufacturer or by the end user during the time frame the manufacturers use the TPEM. Second, the TPEM allows manufacturers to schedule equipment design cycles to coincide 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 several small-volume 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 in an industry-wide database (the Power Systems Research database).[53] This analysis looked at each equipment manufacturer's product offerings by power category and the estimated 2000 U.S. sales of each equipment model. We used this database to analyze how equipment manufacturers can use TPEM to maximize the number of equipment models with delayed redesign until the eighth year of the program (as discussed in Section III.B of the preamble, TPEM provisions allow equipment manufacturers to sell products with uncertified engines until seven years after the applicable Tier 4 standard is implemented.). We specifically analyzed the percent-of-production allowance and the small-volume allowance programs being adopted for the Tier 4 rule (as discussed in the preamble). The results are shown in Table 6.3-9. (It should be noted that the newly adopted technical hardship flexibility provision, which potentially allows an additional 70 percent of equipment manufacturer's sales in a power category to use non-Tier 4 engines for a limited time provided an appropriate case-by-case demonstration of extreme technical hardship is made to EPA, likewise could have associated cost savings.)

Table 6.3-9
Potential Impact of TPEM Program on Equipment Models and Sales (all equipment companies)

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
Percent of all equipment models that could use TPEM for full-seven years	56%	61%	66%	71%	80%	66%
Percent of equipment sales that could use TPEM for full-seven years	7%	10%	13%	12%	21%	10%

[a] Note that the power ranges are 25-75 hp and 75-175 hp. This analysis was done using 70 hp as a cut-point. We believe the results of this analysis would not have been significantly different if the power outpoint had been 75 hp.

This analysis indicates that if fully utilized by equipment manufacturers, 66 percent of nonroad diesel equipment models can 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 their equipment models using 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 6.3-9 indicates that for engines between 25 and 75 hp, 61 percent of all equipment models in this power range can take advantage of the TPEM (i.e., the percent of production allowance and the small volume allowance options) to delay an equipment redesign for seven years. It is important to note that while the TPEM can substantially reduce equipment redesign costs, it is 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 that can be impacted by the TPEM (i.e., the percent of production allowance and the small volume allowance options), which is also shown in Table 6.3-9, is estimated to be no higher than ten percent for no more than seven years.

The analysis presented in Table 6.3-9 is based on the equipment produced by a wide range of equipment manufacturers, both very large, multi-billion dollar corporations as well as small companies who produce a limited number of products. We have performed a similar analysis using only those equipment companies whose data is contained in the PSR database which we were able to identify as small businesses. In some respects the TPEM program, while available to all equipment manufacturers, was designed specifically to benefit small businesses. Within the PSR database, we were able to identify 337 small businesses who together produce more than 2,500 different equipment models. This data was analyzed as described above for Table 6.3-9. The results are shown in Table 6.3-10.

Table 6.3-10
Potential Impact of TPEM Program on Equipment Models and Sales of Small Business Equipment Manufacturers

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
Percent of all equipment models hat could use TPEM for full-seven years	69%	74%	78%	86%	93%	79%
Percent of equipment sales hat could use TPEM for full-seven years	17%	24%	29%	51%	76%	26%

[a] Note that the power ranges are 25-75 hp and 75-175 hp. This analysis was done using 70 hp as a cut-point. We believe the results of this analysis would not have been significantly different if the power outpoint had been 75 hp.

The results in Table 6.3-10 show that in all power categories, the TPEM program provides more flexibility for small business equipment companies than for the equipment industry as a whole. In every power category, the number of equipment models which small companies can delay redesigning for the full seven years is greater than for the industry as a whole, and for the power categories which will likely require engine aftertreatment (i.e., >25hp), approximately 75 percent or more of the equipment models could delay redesign for a full seven years. The actual equipment sales for all of the small business equipment companies which could use the TPEM program under this analysis is 26 percent of the total sales, but in reality this is less than 3 percent of the total nonroad diesel market, as small business companies have a relatively small portion of the total nonroad diesel equipment sales.

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. Section 6.4.1.1 summarizes the total engine fixed costs. Section 6.4.1.2 summarizes the engine variable cost equations for estimating engine variable costs. Section 6.4.1.3 summarizes the engine operating costs. Section 6.4.2.1 summarizes the total equipment fixed costs and 6.4.2.2 summarizes the estimated equipment variable costs. Section 6.4.3 presents these costs on a per unit basis. Note that all present value costs presented here are 30-year numbers (the net present values in 2004 of the stream of costs/reductions occurring from 2007 through 2036, expressed in $2002).

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 are discussed in detail in Section 6.2.1. The total estimated engine fixed costs are summarized in Table 6.4-1. The table also includes 30-year net present values using both a three percent and a seven percent social discount rate.

Table 6.4-1
Summary of Engine Fixed Costs ($2002)

	Incurred Costs ($Million)	Recovered Cost ($Million)	30 Year NPV of Recovered Cost at 3% ($Million)	30 Year NPV of Recovered Cost at 7% ($Million
Engine R&D	$323	$452	$336	$233
Engine Tooling	$74	$91	$70	$50
Engine Certification	$91	$111	$84	$60
Total	$489	$653	$490	$343

6.4.1.2 Engine Variable Costs

Engine variable costs are 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 (see Table 6.2-27). Using these equations, we have calculated the costs for each nonroad diesel engine sold in the year 2000, multiplied that cost by its projected sales during the 30 year period following implementation of the NRT4 program, and then added the future annual costs for each engine to arrive at annual costs during each of those 30 years. We present those annual engine variable costs in Chapter 8. Table 6.4-2 shows the 30-year net present value of those annual costs assuming a three percent social discount rate and a seven percent social discount rate.

Table 6.4-2
30-Year Net Present Value of Engine Variable Costs
($2002)

	30 Year NPVat 3% ($Million)	30 Year NPVat 7% ($Million)
Engine Variable Costs	$13,562	$6,871

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.

Table 6.4-3
Engine Operating Costs Associated with the NRLM Fuel Program
(cents/gallon of 15ppm fuel consumed)

Power category	Oil-Change Savings	CDPF Maintenance	CCV Maintenance	CDPF Regeneration[a]	Net Operating Costs[b]
0<hp<25	(19.3)	0.0	0.0	0.0	(19.3)
25≤hp<50	(8.2)	2.3	0.0	1.3	(4.6)
50≤hp<75	(5.9)	1.6	0.1	1.3	(2.9)
75≤hp<175	(3.3)	0.8	0.3	0.7	(1.5)
175≤hp<300	(2.0)	0.2	0.2	0.7	(0.9)
300≤hp<600	(1.4)	0.1	0.1	0.7	(0.5)
600≤hp<750	(1.1)	0.1	0.2	0.7	(0.1)
>750 hp	(1.1)	0.2	0.2	1.3	0.6
Locomotive/Marine	(1.1)	--	--	--	(1.1)

[a] A one or two percent fuel consumption increase, a 60 cent/gallon baseline fuel price, and a 7.0 cent/gallon incremental fuel cost.

[b] The incremental costs for low-sulfur fuel are presented in Chapter 7.

Engines that make up the existing fleet will realize the oil-change savings shown in Table 6.4-3 while incurring none of the other operating costs, because these engines will not have CDPF or CCV systems. 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 types of equipment and present those in Section 6.5. Aggregate operating costs (the annual total costs) are presented in Chapter 8 and the 30-year net present value of the NRLM fleet operating costs are shown in Table 6.4-4.

Table 6.4-4
30-Year Net Present Value of NRLM Fleetwide Engine Operating Costs
Excluding Fuel Costs
($2002)

	30 Year NPV at 3% ($Million)	30 Year NPV at 7% ($Million)
Engine Operating Costs (a negative value indicates a savings)	-$4,517	-$2,745

6.4.2 Equipment Costs

6.4.2.1 Equipment Fixed Costs

Equipment fixed costs are discussed in detail in Section 6.3.1. Table 6.4-5 shows the estimated equipment fixed costs associated with the Tier 4 emission standards. These figures include estimated costs for equipment redesign and generation of new product support literature.

Table 6.4-5
Summary of Equipment Fixed Costs ($2002)

	Incurred Costs ($Millions)	Recovered Costs ($Millions)	30 Year NPV of Recovered Cost at 3% ($Million)	30 Year NPV of Recovered Cost at 7% ($Million)
Redesign	$801	$1,180	$819	$518
Product Literature	$27	$40	$28	$18
Total	$828	$1,220	$847	$537

6.4.2.2 Equipment Variable Costs

Equipment variable costs are discussed in detail in Section 6.3.2. Using the costs presented there we have calculated the variable costs for the equipment sold in the year 2000 and then projected those costs over the 30 year period following implementation of the NRT4 program. We present those annual equipment variable costs in Chapter 8. Table 6.4-6 shows the 30-year net present value of those annual costs assuming a three percent and a seven percent social discount rate.

Table 6.4-6
30-Year Net Present Value of Equipment Variable Costs
($2002)

	30 Year NPV at 3% ($Million)	30 Year NPV at 7% ($Million)
Equipment Variable Costs	$434	$217

6.4.3 Engine and Equipment Costs on a Per Unit Basis

For the Nonroad Diesel Economic Impact Analysis Model (NDEIM, see Chapter 10), we need engine and equipment costs per unit sold. These per unit costs serve as inputs to the model to determine how the cost increases might impact the quantity of units sold. The costs presented here in Chapter 6 are aggregated in Chapter 8 into annual fleetwide costs during a 30 year period following implementation of the NRT4 program. The annual fleetwide engine fixed costs by power category are shown in Table 8.2-1. The costs presented there represent the annual recovered costs associated with engine R&D, tooling, and certification (note that these costs are also presented in Tables 6.2-6, 6.2-8, 6.2-10, and 6.3-6. As explained earlier in this chapter, the recovered engine R&D costs are revenue weighted, meaning that we have attributed the total industry costs for engine R&D according to our best estimate of revenues from engine sales. Doing this does not impact the resultant total cost of the new Tier 4 standards and only impacts how the costs are allocated to each power range. Such an allocation is of importance only when trying to determine the per unit cost as we are here. Manufacturers may choose to recover their investments in ways different than we have estimated, although recovering investments based on revenues seems like the most likely probability.

Table 6.4-7 shows the per unit costs using this methodology. The values shown in the table are simply the result of dividing the annual costs by power range shown in Table 8.2-1 by the engine sales by power range shown in Table 8.1-1. The costs per unit change from year to year because engine standards are implemented differently in each power category. As more engines across more power categories phase-in to a new set of engine standards, the engine R&D costs are recovered according to a different revenue weighting. Note also that tooling costs within each power range can vary year to year on a per unit basis. This occurs because there are many engine platforms that span different power ranges. Therefore, tooling expenditures done for an engine platform that spans the 100-175 hp and the 175-300 hp ranges would be recovered only on the 175-300 hp engines in 2011 and then on both 100-175 hp and 175-300 hp engines beginning in 2012. Engine fixed costs per unit become zero after several years because the fixed costs invested have been completely recovered.

We can get the engine variable costs per unit in much the same way by dividing the aggregate engine variable costs by power range shown in Table 8.2-3 by the engine sales by power range shown in Table 8.1-1. The results are shown in Table 6.4-8. Note that the engine variable costs per unit continue indefinitely and do not go to zero as do the engine fixed costs shown in Table 6.4-7. Note also that, by 2020, the engine variable costs are not longer changing due to phase-ins, learning curves, or other factors.

Equipment fixed and variable costs per unit can be generated in the same way. Tables 8.3-1 and 8.3-3 present the annual fleetwide equipment fixed and equipment variable costs by power category. Dividing these costs by sales (Table 8.1-1) results in the per unit costs shown in Tables 6.4-9 and 6.4-10 for equipment fixed and equipment variable costs per unit, respectively.

Table 6.4-7
Estimated Engine Fixed Costs per Unit ($2002)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0<hp<25	$ 38	$ 37	$ 36	$ 35	$ 34	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
25<=hp<50	$ 49	$ 48	$ 47	$ 46	$ 45	$ 74	$ 73	$ 71	$ 70	$ 69	$ -	$ -	$ -	$ -	$ -	$ -	$ -
50<=hp<75	$ 50	$ 49	$ 49	$ 48	$ 47	$ 76	$ 75	$ 73	$ 72	$ 71	$ -	$ -	$ -	$ -	$ -	$ -	$ -
75<=hp<100	$ -	$ -	$ -	$ -	$ 80	$ 78	$ 108	$ 106	$ 104	$ 29	$ 28	$ -	$ -	$ -	$ -	$ -	$ -
100<=hp<175	$ -	$ -	$ -	$ -	$ 78	$ 77	$ 106	$ 105	$ 103	$ 29	$ 29	$ -	$ -	$ -	$ -	$ -	$ -
175<=hp<300	$ -	$ -	$ -	$ 225	$ 220	$ 217	$ 290	$ 285	$ 74	$ 73	$ 72	$ -	$ -	$ -	$ -	$ -	$ -
300<=hp<600	$ -	$ -	$ -	$ 527	$ 521	$ 515	$ 735	$ 727	$ 220	$ 218	$ 216	$ -	$ -	$ -	$ -	$ -	$ -
600<=hp<=750	$ -	$ -	$ -	$ 1,156	$ 1,138	$ 1,122	$ 1,630	$ 1,606	$ 509	$ 502	$ 495	$ -	$ -	$ -	$ -	$ -	$ -
>750hp	$ -	$ -	$ -	$ 570	$ 561	$ 553	$ 545	$ 1,447	$ 897	$ 884	$ 872	$ 860	$ -	$ -	$ -	$ -	$ -

Table 6.4-8
Estimated Engine Variable Costs per Unit ($2002)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0<hp<25	$ 129	$ 129	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123
25<=hp<50	$ 147	$ 147	$ 139	$ 139	$ 139	$ 887	$ 887	$ 675	$ 675	$ 675	$ 675	$ 675	$ 675	$ 675	$ 675	$ 675	$ 675
50<=hp<75	$ 167	$ 167	$ 158	$ 158	$ 158	$ 837	$ 837	$ 636	$ 636	$ 636	$ 636	$ 636	$ 636	$ 636	$ 636	$ 636	$ 636
75<=hp<100	$ -	$ -	$ -	$ -	$ 1,133	$ 1,133	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122	$ 1,122
100<=hp<175	$ -	$ -	$ -	$ -	$ 1,375	$ 1,375	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351	$ 1,351
175<=hp<300	$ -	$ -	$ -	$ 1,981	$ 1,981	$ 1,536	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937	$ 1,937
300<=hp<600	$ -	$ -	$ -	$ 2,609	$ 2,609	$ 2,021	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545	$ 2,545
600<=hp<=750	$ -	$ -	$ -	$ 4,944	$ 4,944	$ 3,825	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807	$ 4,807
>750hp	$ -	$ -	$ -	$ 1,973	$ 1,973	$ 1,543	$ 1,543	$ 8,335	$ 8,335	$ 6,734	$ 6,734	$ 6,734	$ 6,734	$ 6,734	$ 6,734	$ 6,734	$ 6,734

Table 6.4-9
Estimated Equipment Fixed Costs per Unit ($2002)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0<hp<25	$ 15	$ 15	$ 14	$ 14	$ 14	$ 13	$ 13	$ 13	$ 12	$ 12	$ -	$ -	$ -	$ -	$ -	$ -	$ -
25<=hp<50	$ 8	$ 8	$ 8	$ 7	$ 7	$ 42	$ 41	$ 40	$ 40	$ 39	$ 32	$ 31	$ 31	$ 30	$ 30	$ -	$ -
50<=hp<75	$ 8	$ 8	$ 8	$ 8	$ 8	$ 44	$ 43	$ 42	$ 42	$ 41	$ 33	$ 33	$ 32	$ 32	$ 31	$ -	$ -
75<=hp<100	$ -	$ -	$ -	$ -	$ 109	$ 107	$ 132	$ 130	$ 128	$ 126	$ 124	$ 122	$ 120	$ 118	$ 24	$ 24	$ -
100<=hp<175	$ -	$ -	$ -	$ -	$ 170	$ 168	$ 207	$ 204	$ 201	$ 197	$ 194	$ 192	$ 189	$ 186	$ 37	$ 37	$ -
175<=hp<300	$ -	$ -	$ -	$ 302	$ 297	$ 291	$ 360	$ 353	$ 348	$ 342	$ 336	$ 331	$ 326	$ 65	$ 64	$ 63	$ -
300<=hp<600	$ -	$ -	$ -	$ 529	$ 523	$ 518	$ 642	$ 635	$ 628	$ 622	$ 615	$ 609	$ 603	$ 121	$ 120	$ 118	$ -
600<=hp<=750	$ -	$ -	$ -	$ 1,210	$ 1,192	$ 1,175	$ 1,451	$ 1,430	$ 1,410	$ 1,390	$ 1,371	$ 1,353	$ 1,335	$ 266	$ 263	$ 259	$ -
>750hp	$ -	$ -	$ -	$ 177	$ 175	$ 172	$ 170	$ 1,377	$ 1,358	$ 1,339	$ 1,320	$ 1,302	$ 1,285	$ 1,114	$ 1,100	$ 1,085	$ 1,072

Table 6.4-10
Estimated Equipment Variable Costs per Unit ($2002)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0<hp<25	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
25<=hp<50	$ -	$ -	$ -	$ -	$ -	$ 20	$ 20	$ 16	$ 16	$ 16	$ 16	$ 16	$ 16	$ 16	$ 16	$ 16	$ 16
50<=hp<75	$ -	$ -	$ -	$ -	$ -	$ 21	$ 21	$ 17	$ 17	$ 17	$ 17	$ 17	$ 17	$ 17	$ 17	$ 17	$ 17
75<=hp<100	$ -	$ -	$ -	$ -	$ 45	$ 45	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48	$ 48
100<=hp<175	$ -	$ -	$ -	$ -	$ 46	$ 46	$ 49	$ 49	$ 49	$ 49	$ 49	$ 49	$ 49	$ 49	$ 49	$ 49	$ 49
175<=hp<300	$ -	$ -	$ -	$ 58	$ 58	$ 46	$ 62	$ 62	$ 62	$ 62	$ 62	$ 62	$ 62	$ 62	$ 62	$ 62	$ 62
300<=hp<600	$ -	$ -	$ -	$ 110	$ 110	$ 88	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117	$ 117
600<=hp<=750	$ -	$ -	$ -	$ 116	$ 116	$ 92	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123	$ 123
>750hp	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 123	$ 123	$ 98	$ 98	$ 98	$ 98	$ 98	$ 98	$ 98	$ 98

6.5 Weighted Average Costs for Example Types of Equipment

6.5.1 Summary of Costs for Some Example Types of Equipment

To better illustrate the engine and equipment cost impacts for this final rule, we have chosen several types of equipment and present the estimated costs for them using weighted average inputs—horsepower, displacement, number of cylinders, etc. Using these sales weighted inputs, we can calculate the costs for these types of equipment in several power ranges and better illustrate the cost impacts of the new emission standards. For the weighted average inputs, we have used the PSR database and determined the sales weighted averages of various parameters of interest. These results are shown in Table 6.5-1. We can use the sales weighted average inputs shown in Table 6.5-1 along with the engine variable cost equations presented in Table 6.4-2 to generate the sales weighted average engine variable costs within each power range (doing so will match the costs presented in Table 6.4-8). For engine fixed costs per unit and equipment fixed and variable costs per unit, we can use the costs per unit presented in Tables 6.4-7, 6.4-9, and 6.4-10, respectively.

These results are presented in Table 6.5-2. Costs presented are near-term and long-term costs for the final standards to which engines in each power category must comply. Long-term costs include only variable costs and therefore represent costs after all fixed costs have been recovered. Note that not all engines in each power category would incur all the costs shown in the table. For example, only turbocharged engines will add a CCV system as a result of the NRT4 final rule—it is important to remember that the costs presented in Table 6.5-2 are sales weighted averages within each power range. Included in Table 6.5-2 are estimated operating costs for each power range, again using the sales weighted average inputs shown in Table 6.5-1 along with information presented in Tables 6.2-29 through 6.2-31 and the fuel economy impacts discussed in section 6.2.3.3.

We can compare these sales weighted average costs by power range to the typical price of various types of equipment—construction, agricultural, pumps & compressors, gensets & welders, refrigeration & A/C, general industrial, and lawn & garden. We have estimated the prices of these equipment using a linear relationship between the price for these types of equipment and their power.[54] Table 6.5-3 shows the resultant equipment prices. Table 6.5-4 shows the near-term and long-term costs (Table 6.5-2) as a percentage of equipment prices (Table 6.5-3).

Table 6.5-1
Sales Weighted Average Inputs for Engine & Equipment Costs ($2002)

	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
Sales Weighted Displacement (L)	0.753	1.650	2.592	3.872	4.916	7.773	10.755	21.854	41.968
Sales Weighted # Cylinders	2.2	3.1	3.8	4.0	4.7	6.0	6.1	9.5	11.8
Sales Weighted Hp	16.9	36.6	57.1	83.3	126.6	224.8	363.7	728.7	1335.3
% Naturally Aspirated	100%	98%	91%	75%	13%	1%	0%	0%	0%
% Turbo	0%	2%	9%	25%	87%	99%	100%	100%	100%
% DI	33%	41%	85%	98%	100%	100%	100%	100%	100%
% IDI	67%	59%	15%	2%	0%	0%	0%	0%	0%

%DI and %IDI refer to the percentage of engines that have a direct injection fuel system and the percentage that have an indirect injection fuel system.

Table 6.5-2
Sales Weighted Average Near-Term and Long-Term Costs by Power Category[a]
($2002, for the final emission standards to which the equipment must comply)

	0<hp<25	25<=hp<50	50<=hp<75	75<=hp<100	100<=hp<175	175<=hp<300	300<=hp<600	600<=hp<=750	>750 hp
Near-term costs calculated in the year:	2008	2013	2013	2012	2012	2011	2011	2011	2015
Engine variable costs									
Fuel System	$0	$182	$184	$0	$0	$0	$0	$0	$0
EGR	$0	$136	$0	$0	$0	$0	$0	$0	$1,451
CCV*	$0	$1	$3	$10	$39	$49	$56	$79	$91
CDPF	$0	$316	$454	$642	$795	$1,213	$1,649	$3,274	$6,218
CDPF regen system	$0	$259	$198	$190	$197	$226	$256	$370	$575
NOx adsorber	$0	$0	$0	$583	$691	$986	$1,294	$2,442	$0
DOC	$129	$0	$0	$0	$0	$0	$0	$0	$0
Engine Fixed Costs									
R&D	$15	$51	$54	$50	$51	$126	$414	$1,023	$861
Tooling	$8	$7	$6	$16	$16	$69	$76	$72	$107
Cert	$15	$16	$16	$14	$12	$29	$37	$61	$478
Equipment Variable Costs	$0	$20	$21	$45	$46	$58	$110	$116	$123
Equipment Fixed Costs	$15	$42	$44	$109	$170	$302	$529	$1,210	$1,377
Near-term Total Engine & Equipment Costs	$180	$1,030	$980	$1,660	$2,020	$3,060	$4,420	$8,650	$11,280
Long-term Total Engine & Equipment Costs in the year 2030	**$120**	**$700**	**$650**	**$1,170**	**$1,400**	**$2,000**	**$2,660**	**$4,930**	**$6,830**
Operating Costs (discounted lifetime $)									
Fuel Costs	$110	$260	$650	$910	$1,390	$2,290	$4,890	$11,780	$23,110
Oil Change Costs (Savings)	-$310	-$310	-$550	-$430	-$660	-$640	-$980	-$1,900	-$3,790
System regenerations	$0	$50	$120	$90	$130	$220	$470	$1,130	$4,430
CCV maintenance	$0	$0	$10	$30	$50	$70	$100	$300	$620
CDPF maintenance	$0	$90	$140	$100	$150	$70	$80	$240	$500
Total Incremental Operating Costs (Savings)	**-$200**	**$90**	**$370**	**$710**	**$1,070**	**$2,000**	**$4,560**	**$11,550**	**$24,870**
Baseline Operating Costs (fuel and oil only)	$2,170	$3,410	$7,630	$9,490	$13,400	$21,360	$44,980	$108,430	$212,720

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. For 25 to 75 hp engines, CCV costs in 2013 will be long term because CCV systems are first required in 2008.

Table 6.5-3
Sales Weighted Average Prices for Various Types of Equipment ($2002)

	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
Construction Equipment	$ 18,000	$ 29,700	$ 31,600	$ 57,900	$ 122,700	$ 247,300	$ 431,400	$ 717,500	$ 976,900
Agricultural Equipment	$ 6,900	$ 14,400	$ 22,600	$ 33,400	$ 69,100	$ 125,900	$ 175,900	NA	NA
Pumps & Compressors	$ 6,000	$ 12,200	$ 10,600	$ 12,500	$ 23,800	$ 37,500	$ 81,000	NA	NA
GenSets & Welders	$ 6,800	$ 8,700	$ 8,300	$ 18,000	$ 21,400	$ 33,500	$ 39,500	NA	NA
Refrigeration & A/C	$ 12,500	---	---	NA	NA	NA	NA	NA	NA
General Industrial	$ 17,300	$ 42,300	$ 56,400	$ 74,300	$ 116,900	$ 141,700	$ 176,700	$ 268,800	$ 421,900
Lawn & Garden	$ 9,300	$ 21,500	$ 33,100	$ 38,500	$ 29,900	$ 52,700	$ 85,100	NA	NA

Table 6.5-4
Estimated Costs as a Percentage of New Equipment Price

	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
Near-term Cost to Price Ratio									
Construction Equipment	1%	3%	3%	3%	2%	1%	1%	1%	1%
Agricultural Equipment	3%	7%	4%	5%	3%	2%	3%		
Pumps & Compressors	3%	8%	9%	13%	8%	8%	5%		
GenSets & Welders	3%	12%	12%	9%	9%	9%	11%		
Refrigeration & A/C	1%								
General Industrial	1%	2%	2%	2%	2%	2%	3%	3%	3%
Lawn & Garden	2%	5%	3%	4%	7%	6%	5%		
Long-term Cost to Price Ratio									
Construction Equipment	1%	2%	2%	2%	1%	1%	1%	1%	1%
Agricultural Equipment	2%	5%	3%	4%	2%	2%	2%		
Pumps & Compressors	2%	6%	6%	9%	6%	5%	3%		
GenSets & Welders	2%	8%	8%	7%	7%	6%	7%		
Refrigeration & A/C	1%								
General Industrial	1%	2%	1%	2%	1%	1%	2%	2%	2%
Lawn & Garden	1%	3%	2%	3%	5%	4%	3%		

* Note that the above percentages include equipment cost estimates that are averaged across all equipment types (i.e, motive and non-motive equipment). Our redesign estimates for non-motive equipment are lower than for motive equipment (see Table 6.3-2). Therefore, the near-term percentages for non-motive equipment types (e.g., gensets, pumps, etc.), are skewed slightly high just as the near-term percentages for motive equipment types are skewed slightly low. As a result, the long-term percentages, that represent the percentages after all fixed costs like engine R&D and equipment redesign have been recovered and are no longer part of the estimated cost, are probably better representations of the possible effect of the rule on equipment prices.

6.5.2 Method of Generating Costs for a Specific Piece of Equipment

To facilitate the effort to duplicate this example analysis for specific pieces of equipment, this section will briefly describe the necessary steps to create the cost analysis based on the information in this document.

The first step required to develop an estimate of our projected cost for control under the 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 of combustion system used by the engine (i.e., indirect-injection, IDI, or direct-injection, DI);
- model year of production; and,
- the power category of the engine.

With this information and the data tables elsewhere in this document, it is possible to estimate the costs of meeting the new standards for any particular piece of equipment.

As an example, we will estimate the cost of compliance for a 76 hp backhoe in the year 2012. The first step is to define our engine characteristics, as shown in Table 6.5-6.

Table 6.5-6
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
Power 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	$50	Table 6.2-6 Engine R&D Costs (per engine)
Engine Tooling	$16	Table 6.2-8 Engine Tooling Costs (per engine)
Engine Certification	$14	Table 6.2-10 Engine Certification Costs (per engine)
Total Engine Fixed	$80	Summation (see also Table 6.4-7)
Total Equipment Fixed	$109	Table 6.4-9 Equipment Fixed Cost per Unit
Total Fixed Costs	$189	Summation

The engine variable costs are related to specific engine technology characteristics in a series of linear equations described in table 6.2-27. The table includes all the different variable cost components for different size ranges of engines meeting applicable emission 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 that 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	\$103(x) + \$183 \$83(x) + \$160	Displacement[b]	>75 hp engines according to phase-in of NRT4 NOx std.
2012 76hp Backhoe	2012 is Near Term	\$103 (3.9)+\$183 = \$585	3.9 liters	In 2012 a 76 hp engine in the NOx phase-in set will require a NOx adsorber
CDPF System	Near term Long term	\$146(x) + \$75 \$112(x) + \$57	Displacement	>25 hp engines according to NRT4 PM std.
2012 76hp Backhoe	2012 is Near Term	\$146(3.9)+\$75= \$644	3.9 liters	In 2012 all 76hp engines are projected to require CDPFs
CDPF Regen System – IDI engines	Near term Long term	\$20(x) + \$293 \$16(x) + \$223	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 combustion system, not indirect-injection
CDPF Regen System – DI engines	Near term Long term	\$10(x) + \$147 \$8(x) + \$111	Displacement	DI engines adding a CDPF
2012 76hp Backhoe	2012 is Near Term	\$10(3.9)+\$147= \$186	3.9 liters	The example engine is a DI engine and has a CDPF
DOC	Near term Long term	\$18(x) + \$116 \$18(x) + \$110	Displacement	<25 hp engines beginning in 2008; 25-75 hp 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) + \$34 \$2(x) + \$24	Displacement	All turbocharged engines when they first meet a Tier 4 PM std.
2012 76hp Backhoe	2012 is Near Term	\$2(3.9)+\$34= \$42	3.9 liters	The example engine is turbocharged
Cooled EGR System	Near term Long term	\$43(x) + \$65 \$33(x) + \$48	Displacement	25-50 hp engines beginning in 2013; >750hp engines beginning in 2011
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	\$78(x) + \$636 \$58(x) + \$484	# 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	\$67(x) + \$178 \$50(x) + \$134	# 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 and 2; Long term = years 3+. Explanation of near term and long term is 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 $1457 (Note that this value of $1457 differs from the value shown in Table 6.4-8 due to that value being based on only 50 percent of engines in this power range adding a NOx adsorber in 2012). The equipment variable costs are presented in table 6.4-10 and are referenced by engine power category. For the 76hp example here, the estimated equipment variable costs are $45.

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 estimated here. The resulting total is $1691 ($189 + $1457 + $45, note that rounding may result in slightly different results). Typically we have presented these total cost estimates to the nearest ten dollars.

6.5.3 Costs for Specific Examples from the Proposal

In the proposal, we developed costs and prices for several specific example pieces of equipment. Here we recreate that analysis using the costs presented above for the final rule. Table 6.5-5 shows these results. For this table, we have used the same engine and equipment related inputs (power, displacement, etc.) as was used in Table 6.5-1 of the draft RIA to facilitate the comparison.[S]

[S] Another important point here is that we have used the same load factor, activity, and fuel consumption inputs, etc., that were used in the draft RIA to ensure a fair comparison of operating cost differences between the draft analysis and the final analysis. Note also that the inputs used for the values shown in Table 6.5-5 are for the specific pieces of equipment and are not the sales weighted inputs used to generate the operating costs shown in Table 6.5-2, this explains the different results.

Table 6.5-5
Near Term and Long Term Costs for Several Example Pieces of Equipment[a]
($2002, 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	$790	$1,200	$2,560	$1,970	$4,140	$4,670
Near Term	$180	$1,160	$1,700	$3,770	$3,020	$6,320	$8,610
Estimated Equipment Price[b]	$4,000	$20,000	$49,000	$238,000	$135,000	$618,000	$840,000
Incremental Operating Costs[c]	-$80	$70	$610	$2,480	$2,110	$7,630	$20,670
Baseline Operating Costs (Fuel & Oil only)[c]	$940	$2,680	$7,960	$27,080[d]	$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. Updated prices for the final analysis taken from, "Price Database for New Non-road Equipment," memorandum from Zuimdie Guerra to docket A-2001-28.[55]
c. Present value of lifetime costs.
d. This value corrects an error that existed in the draft RIA where we incorrectly reported the baseline operating cost as $77,850 (the value for the 503 hp dozer).

6.6 Residual Value of Platinum Group Metals

One element not considered in our cost analysis is the residual value of the platinum group metals (PGMs) in the aftertreatment devices that may be added to comply with the new engine standards. These devices cannot be lawfully removed at the end of an engine's life and reused on a new engine or piece of equipment due to deterioration and/or agglomeration of the PGMs. However, virtually all of the PGMs contained in the devices will remain there and can be removed and recycled back into the open market for use in new aftertreatment devices. This represents a residual value to these metals much like the residual value to many other parts of a truck headed for scrappage. Typically, today, the item of greatest residual value would be the engine which can be removed from an old vehicle/truck prior to scrappage, rebuilt, and then sold back into the market. This same thing can be expected to happen with the PGMs installed in the aftertreatment devices.

From experts in the field,[56, 57] we learned that there are as many as 50 major used/spent auto catalyst collection sites in the United States. Further, roughly 80 percent of spent auto catalysts are recycled in the US (only 30 percent are recycled currently in Europe, a percentage that will presumably increase as more PGM containing devices are used in Europe). We also learned that only one to two percent of platinum is lost during the recovery process and the same is true for paladium. For rhodium, as much as 10 percent is lost during the recovery process.

We can estimate the residual value of PGMs being used to comply with the Tier 4 standards by using the PGM loadings and the aftertreatment device volumes we have estimated will be used (see section 6.2.2). Doing this results in a 30-year net present value, assuming a three percent discount rate, of $3 billion (using the NRT4 PGM prices). This is roughly 20 percent of the $13.6 billion engine variable costs we have estimated. But, according to experts in the field, we cannot expect all of this value to be returned to the market. To be conservative, we have assumed that 80 percent of aftertreatment devices would be recycled and that 98 percent of the platinum in those devices would be recovered and returned to the market while only 90 percent of the rhodium would be recovered and returned to the market. Further, we have assumed that ten percent of the residual value would be kept by the recycler to cover costs associated with recycling the material (i.e., energy use, labor, and profit).[58] We must also consider the time gap between installation on a new truck and recovery. For these calculations, we used the average lifetimes by power category from our NONROAD model and assumed that, at the end of those lifetimes, 80 percent of devices would be recovered. In this way, we calculate a net present value of PGMs recovered in the year they first enter the new truck market. We have done this for each of the 30 years following implementation of the Tier 4 standards giving us a series of present values of recovered PGMs for each of 30 years. Note that, when accounting for the latency period between the new equipment purchase and the ultimate recycling, we have used a seven percent discount rate rather than three percent. Had we used a three percent rate, the savings would have been higher. Table 6.6-1 shows these results along with the total annual engine variable costs for comparison (see Table 8.2-3).

The table shows that the residual value of PGMs could amount to a 30-year net present value savings of roughly $1.2 billion, assuming a three percent social discount rate. Note that, while we have estimated the residual value at $1.2 billion versus PGM use of $3 billion, this does not mean that only 40 percent of PGMs are actually returned to the market. Instead, it means that the present value of PGMs recovered are 40 percent of the value of those initially used. By our estimation, nearly 80 percent of platinum will be recovered (98% of 80%) and just over 70 percent of rhodium will be recovered (90% of 80%). Note also that, to remain conservative in our cost estimates, we have not used these estimates in any of our cost per ton or our benefit-cost analyses. We have presented them here only for the information of the reader.

Table 6.6-1
Potential Impact of PGM Recovery on Costs
($Millions of 2002 dollars)

Year	Engine Variable Costs (including PGMs)	PGM Costs	PV of PGMs Recovered
2008	$ 62	$ 2	$ (1)
2009	$ 63	$ 2	$ (1)
2010	$ 61	$ 2	$ (1)
2011	$ 340	$ 59	$ (22)
2012	$ 637	$ 113	$ (46)
2013	$ 798	$ 130	$ (54)
2014	$ 864	$ 186	$ (76)
2015	$ 839	$ 193	$ (79)
2016	$ 852	$ 196	$ (80)
2017	$ 860	$ 199	$ (82)
2018	$ 873	$ 202	$ (83)
2019	$ 887	$ 205	$ (84)
2020	$ 900	$ 208	$ (85)
2021	$ 913	$ 211	$ (87)
2022	$ 927	$ 214	$ (88)
2023	$ 940	$ 217	$ (89)
2024	$ 954	$ 220	$ (90)
2025	$ 967	$ 223	$ (92)
2026	$ 980	$ 226	$ (93)
2027	$ 994	$ 229	$ (94)
2028	$ 1,007	$ 232	$ (95)
2029	$ 1,021	$ 234	$ (97)
2030	$ 1,034	$ 237	$ (98)
2031	$ 1,048	$ 240	$ (99)
2032	$ 1,061	$ 243	$ (100)
2033	$ 1,074	$ 246	$ (102)
2034	$ 1,088	$ 249	$ (103)
2035	$ 1,101	$ 252	$ (104)
2036	$ 1,115	$ 255	$ (105)
30 Yr NPV at 3%	$ 13,562	$ 2,996	$ (1,231)
30 Yr NPV at 7%	$ 6,871	$ 1,488	$ (611)

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