United States Environmental Protection Agency | Air and Radiation | EPA420-R-02-021 August 2002

Final Technical Support Document: Nonconformance Penalties for 2004 Highway Heavy Duty Diesel Engines

EPA420-R-02-021
August 2002

Final Technical Support Document: Nonconformance Penalties for 2004 Highway Heavy Duty Diesel Engines

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

Table of Contents

Table of Contents

CHAPTER 1: INTRODUCTION

The Technical Support Document (TSD) for this rulemaking presents analyses and supporting data for the provisions EPA used for establishing nonconformance penalties for model year 2004 and later on-highway heavy duty diesel engines.

I. Background on Nonconformance Penalties

A. Clean Air Act Requirements

Section 206(g) of the Clean Air Act (the Act), 42 U.S.C. 7525(g), requires EPA to establish nonconformance penalties for HDEs or HDVs which exceed the applicable emissions standard, provided that their emissions do not exceed an appropriate upper limit. Congress adopted section 206(g) in the Clean Air Act Amendments of 1977 as a response to perceived potential for problems with technology-forcing heavy-duty emissions standards. Following International Harvester v. Ruckelshaus, 478 F.2d 615 (D.C. Cir. 1973), Congress realized the dilemma that technology-forcing standards were likely to cause. If strict standards were maintained, then some manufacturers, "technological laggards," might be unable to comply initially and would be forced out of the marketplace. NCPs were intended to remedy this potential problem. The laggards would have a temporary alternative that would permit them to sell their engines or vehicles by payment of a penalty. At the same time, conforming manufacturers would not suffer an economic disadvantage compared to nonconforming manufacturers, because the NCP would be based, in part, on money saved by the technological laggard and its customer from the nonconforming engine or vehicle. The resulting provisions of the Act require that NCPs account for the degree of emission nonconformity; increase periodically to provide incentive for nonconforming manufacturers to achieve the emission standards; and, most importantly, remove any competitive disadvantage to conforming manufacturers.

Under section 206(g)(1), NCPs may be offered for HDVs or HDEs. The penalty may vary by pollutant and by class or category of vehicle or engine. HDVs are defined by section 202(b)(3)(C) as vehicles in excess of 6,000 pounds gross vehicle weight rating (GVWR). The light-duty truck (LDT) classification includes trucks that have a GVWR of 8500 lbs or less. Therefore, certain LDTs may be classified as HDVs. Historically, LDTs up through 6000 lbs GVWR have been considered "light light-duty trucks" (LLDTs) and LDTs between 6,001 and 8,500 pounds GVWR have been considered "heavy light-duty trucks" (HLDTs). Based on various new requirements established by the Clean Air Act Amendments of 1990, each of these two light truck categories has been further subdivided into groups by weight. The LLDTs are classified by weight based on "loaded vehicle weight," or LVW, which maintains its current definition: curb weight plus 300 lbs. The trucks up through 3750 lbs LVW make up a subclass called light-duty-trucks-1, or LDT1. Those greater than 3750 lbs LVW but less than or equal to 6000 lbs GVWR are the subclass light-duty-trucks-2, or LDT2. The HLDTs are divided at 5750 lbs "adjusted loaded vehicle weight," or ALVW. Adjusted loaded vehicle weight is the average of the curb weight and the GVWR. The HLDTs that are up through 5750 lbs ALVW are called light-duty trucks-3, or LDT3. Those above 5750 lbs ALVW but less than or equal to 8500 lbs GVWR are light-duty-trucks-4, or LDT4. The LDT3 and LDT4 subclasses make up the HLDT vehicle class.

Section 206(g) authorizes EPA to require testing of production vehicles or engines in order to determine the emission level on which the penalty is based. If the emission level of a vehicle or engine exceeds an upper limit of nonconformity established by EPA through regulation, the vehicle or engine would not qualify for an NCP under section 206(g) and no certificate of conformity could be issued to the manufacturer. If the emission level is below the upper limit but above the standard, that emission level becomes the "compliance level," which is also the benchmark for warranty and recall liability; the manufacturer who elects to pay the NCP is liable for vehicles or engines that exceed the compliance level in-use, unless, for the case of HLDTs, the compliance level is below the in-use standard. The manufacturer does not have in-use warranty or recall liability for emissions levels above the standard but below the compliance level.

B. Previous NCP Rulemakings and Regulations

The generic NCP rule (Phase I) was promulgated August 30, 1985 (50 FR 35374). It established regulations for calculating NCPs in 40 CFR Part 86 Subpart L. It also established three basic criteria for determining the eligibility of emission standards for nonconformance penalties in any given model year. First, the emission standard in question must become more difficult to meet. This can occur in two ways, either by the emission standard itself becoming more stringent, or due to its interaction with another emission standard that has become more stringent. Second, substantial work must be required in order to meet the emission standard. EPA considers "substantial work" to mean the application of technology not previously used in that vehicle or engine class/subclass, or a significant modification of existing technology, in order to bring that vehicle/engine into compliance. EPA does not consider minor modifications or calibration changes to be classified as substantial work. Third, a technological laggard must be likely to develop. A technological laggard is defined as a manufacturer who cannot meet a particular emission standard due to technological (not economic) difficulties and who, in the absence of NCPs, might be forced from the marketplace. EPA will make the determination that a technological laggard is likely to develop, based in large part on the above two criteria. However, these criteria are not always sufficient to determine the likelihood of the development of a technological laggard. An emission standard may become more difficult to meet and substantial work may be required for compliance, but if that work merely involves transfer of well-developed technology from another vehicle class, it is unlikely that a technological laggard would develop.

The above criteria were used to determine eligibility for NCPs during Phase II of the NCP rulemaking process (50 FR 53454, December 31, 1985). NCPs were offered for the following 1987 and 1988 model year standards: the particulate matter (PM) standard for 1987 diesel-fueled light-duty trucks with loaded vehicle weight in excess of 3750 pounds (LDDT2s), the 1987 gasoline-fueled light HDE (LHDGE) HC and CO emission standards, the 1988 diesel-fueled HDE (HDDE) PM standard, and the 1988 HDDE NOx standard. As discussed in the Phase II rule, NCPs were considered, but not offered, for the 1987 HLDT NOx standard and the 1988 (later, the 1990) gasoline-fueled HDE (HDGE) NOx standard.

The availability of NCPs for 1991 model year HDE standards was addressed during Phase III of the NCP rulemaking (55 FR 46622, November 5, 1990). NCPs were offered for the following: the 1991 HDDE PM standard for petroleum-fueled urban buses, the 1991 HDDE PM standard for petroleum-fueled vehicles other than urban buses, the 1991 petroleum-fueled HDDE NOx standard, and the PM emission standard for 1991 and later model year petroleum-fueled light-duty diesel trucks greater than 3750 lbs loaded vehicle weight (LDDT2s). As discussed in the Phase III rule, NCPs were also considered, but not offered for the methanol-fueled heavy-duty diesel engine and heavy-duty gasoline engine standards as it was concluded that those standards did not meet the eligibility criteria established in the generic rule. In addition, Phase III of the NCP rulemaking described how NCPs would be integrated into the HDE NOx and PM averaging program.

The availability of NCPs for HDVs and HDEs subject to the 1994 and later model year emission standards for particulate matter (PM) was addressed by Phase IV of the NCP rulemaking (58 FR 68532, December 28, 1993). NCPs were offered for the following: the 1994 and later model year PM standard for heavy-duty diesel engines (HDDEs) used in urban buses, and the 1994 and later model year PM standard for HDDEs used in vehicles other than urban buses. NCPs were also considered, but not offered, for the 1994 and later model year methanol-fueled HDE PM standard and the 1994 and later model year cold carbon monoxide (CO) standard for heavy light-duty gasoline fueled trucks.

The availability of NCPs for HDVs and HDEs subject to the 1998 and later model year emission standards for NOx was addressed by Phase V of the NCP rulemaking (61 FR 6949, February 23, 1996). NCPs were offered for the following: the 1998 and later model year NOx standard for heavy duty diesel engines (HDDEs), the 1996 and later model year for Light-Duty Truck 3 (LDT3) NOx standard, and the 1996 and later urban bus PM standard. A concurrent but separate final rule (61 FR 6944, February 23, 1996) established NCPs for the 1996 LDT3 PM standard and discussed other standards for which NCPs were considered.

II. Promulgation of 2004 Emission Standards

A. 1997 FRM

On October 21, 1997, EPA issued a final rule (62 FR 54694). The rule established a NOx + NMHC standard of 2.4 g/bhp-hr (or 2.5 g/bhp-hr with a 0.5 g/bhp-hr NMHC cap) for 2004 and later model year heavy-duty diesel-cycle engines. The rule also adopted other related compliance provisions for diesel-cycle heavy-duty engines beginning with the 2004 model year, as well as revisions to the useful life for the heavy-heavy duty diesel engine service class. The feasibility and cost-effectiveness analyses for that rule were described in the 1997 Regulatory Impact Analysis (RIA). We have placed a copy of the 1997 RIA into the docket for this rulemaking.

B. 2000 FRM

The 1997 FRM included a commitment by EPA to review in 1999 the technological feasibility of the NMHC+NOx standard and its appropriateness under the Clean Air Act. EPA published an FRM in 2000 that reaffirmed the technical and economic feasibility of the 2004 model year diesel NOx + NMHC standard (64 FR 58472, October 29, 1999). The reanalysis of the feasibility and cost-effectiveness of these standards were described in the 2000 Regulatory Impact Analysis (RIA). That 2000 RIA can be found in the docket for this rulemaking.

III. Characterization of the Heavy duty Engine and Vehicle Industries

A. Vehicle Applications and Classes

Heavy duty engines are used in a wide variety of vehicle applications. Smaller engines are used in large pickup trucks, vans and other vehicles using those same chassis. At the other extreme, the largest engines are used in cement mixers, garbage trucks, and line-haul trucks. In matching the engines to the vehicles, the minimum requirement is that the engine would be large enough to power a fully-loaded truck up a hill. More typically, especially for the larger trucks, the engine is selected to provide the best fuel consumption. In other cases, especially for light-heavy duty, larger engines are used to provide additional performance.

In applying heavy duty emission standards, EPA categorizes heavy duty vehicles into three classes: light-heavy duty; medium-heavy duty; and heavy-heavy duty. Light-heavy duty includes pickup trucks and vans. Medium-heavy duty includes delivery trucks and recreational vehicles (CVS). Heavy-heavy duty includes buses and line-haul trucks.

Table 1-1
Service Classes of Heavy Duty Vehicles

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

B. Engine and Vehicle Manufacturers

Table 1-2 shows the major heavy duty engine and vehicle manufacturers for the U.S. and Canada. It also illustrates the degree to which vehicle manufacturers buy engines from different engine manufacturers. The industry operates so that the vehicle manufacturer decides during the design stage which engines it will make available in its vehicles, and the ultimate customer chooses its engine from among the available options. The result is that most of the vehicle manufacturers use engines from two or more engine suppliers. This practice make the industry a very competitive marketplace. This is particularly true for the medium-heavy and heavy-heavy market place. The light-heavy market is dominated by exclusive relationships between vehicle manufacturers and engine manufacturers, specifically: General Motors historically supplied their own diesel engines in the light-heavy pick-up trucks offered by GC and Chevrolet (such a relationship continues today between General Motors and Isuzu); Ford exclusively offers Navistar/International diesel engines in their light-heavy pick-up truck and van models, and DaimlerChrysler subsidiary Dodge exclusively uses Cummins supplied diesel engines in their light-heavy pick-up trucks. However, in the medium-heavy and heavy-heavy vehicle market, there is a wide range of engines available to choose from for the same vehicle, for example, a end-user can purchase a Western Star vehicle with either a Caterpillar, Cummins, or a Detroit Diesel engine in it. In this sense, it has been common practice in the medium-heavy and heavy-heavy marketplace to treat the engine almost as a commodity.

Table 1-2
1999 U.S./Canada Diesel Engine Market Share[1]

Vehicle Make	Engine Manufacturer								
	Caterpillar	Cummins	Detroit Diesel	GM	Mack	Mercedes Benz	Navistar	Volvo	Total
Chevrolet	18.9			81.1					100
Dodge		100							100
Ford							100		100
Freightliner	27.3	41.9	30.3			0.4			100
GC	52.2			47.8					100
Kenworth	57.9	28	14.1						100
Mack	0.1	0.1			99.8				100
Navistar	7	18.2	8.4				66.4		100
Peterbuilt	68.5	19.6	11.9						100
Sterling	70.4	21.7	7.8						100
Volvo	0.1	51.3	32.1					16.4	100
Western Star	59	21.9	18.1						99
Other	18.3	64.2	12.8		4.8				100
12-Mos.1999	17.4	20.4	9.3	6.8	4.8	0.1	40.4	0.7	100

Table 1-3 contains an estimate of the factory sales of diesel engines into the heavy duty market for the major truck manufacturers in the U.S. as well as Canada. This table indicates that, for the light heavy market, Ford dominates the sales of diesel-powered vehicles with nearly 70 percent, while General Motors and DaimlerChrysler each roughly split the remaining 30 percent between them. In the medium-heavy duty truck market, International (formerly Navistar) controls nearly 40 percent of the market, followed by DaimlerChrysler with 26 percent (mostly from the Freightliner subsidiary), GM and Ford with roughly 17 percent each, and Paccar's two units Kenworth and Peterbuilt each with under 1 percent. The heavy-heavy duty truck market contains a wider diversity of truck manufacturers. In the heavy-heavy duty market DaimlerChrysler has the largest share with approximately 38 percent (Western Star is now a subsidiary of DaimlerChrysler), of which nearly 30 percent comes from Freightliner. The next largest heavy-heavy duty truck manufacturer is Paccar with 21 percent of the market, which is divided approximately equally between it's two subsidiaries Kenworth and Peterbuilt. The rest of the heavy duty truck market is divided between International, Mack and Volvo, which have approximately 17, 13, and 12 percent of the market respectively. Table 1-3 illustrates that in a similar manner to the HD engine market, the HD truck market is a competitive marketplace with a number of players, particularly in the medium-heavy duty and heavy-heavy duty categories.

Table 1-3
1999 U.S./Canada Factory Sales of Diesel Trucks[2]

	Light-Duty		Medium-Duty		Heavy Duty	
Manufacturer	**Units**	**% Total**	**Units**	**% Total**	**Units**	**% Total**
Total DaimlerChrysler	43,643	14.5		26.4	107,592	35.5
Dodge	*42,832*	*14.2*	-	-	-	
Freightliner	*811*	*0.3*	*44,548*	*23.2*	*88,338*	*29.1*
Sterling	-	-	*6,214*	*3.2*	*19,254*	*6.4*
Ford	208,314	69.2		16.7	-	-
Total General Motors	48,923	16.3		17.6	-	-
Chevrolet	*32,817*	*10.9*	*9,955*	*5.2*	-	-
GMC	*16,106*	*5.4*	*23,911*	*12.5*	-	-
Mack	-	-			38,528	12.7
Navistar/International	-	-		37.8	50,151	16.5
Total Paccar	-	-	2,745	1.4	63,746	
Kenworth	-	-	*1,298*	*0.7*	*32,320*	*10.7*
Peterbuilt	-	-	*1,447*	*0.8*	*31,426*	*10.4*
Volvo	-	-	-	-	34,751	11.5
Western Star	-	-	-	-	7,207	2.4
Other	-	-	-	-	1,175	0.4
1999 Totals	**300,880**	**100**		**100**	**303,150**	**100**

IV. Heavy Duty Diesel Consent Decrees

On October 22, 1998, the Department of Justice and the Environmental Protection Agency announced settlements with seven major manufacturers of diesel engines. The settlements resolved claims that they installed illegal computer software on heavy duty diesel engines that turned off the engine emission control system during highway driving. The settlements were entered by the Court on July 1, 1999.

These Consent Decrees are relevant with respect to this rulemaking because of their impact on the heavy-heavy duty diesel engines sold in the U.S. today. The Consent Decrees allow currently certified heavy-heavy service class diesel engines to continue to use emission control strategies which result in very high NOx emissions when the engines operate in the real world. Even though these engines pass the current FTP emission standard of 4.0 g/bhp-hr NOx when operated over the FTP duty-cycle in the laboratory, when operated in-use these engines can have NOx emission levels as high as 6 or even 7 g/bhp-hr NOx. The heavy-heavy market place is dominated by Consent Decree companies, such that the vast majority (>95%) of model year 2000 heavy-heavy engines produced for the U.S. market were manufactured by Consent Decree companies. As specified in the Consent Decrees, these heavy-heavy service class engines must currently comply with the 4.0 g/bhp-hr NOx standard when tested over the FTP, and in addition they also must meet an emission limit of 6.0 g/bhp-hr NOx when tested over the Euro-3 steady-state test cycle, and an emission limit of 7.0 g/bhp-hr NOx when tested for compliance with the not-to-exceed test limits.[3] The docket for this rulemaking contains a memorandum summarizing engine certification data for model year 2001 heavy duty diesel engine families which includes test data from both the FTP and the Euro-3 test procedures.[4] The "baseline" engine which these companies will need to modify in order to comply with the 2004 FTP standard and the defeat device prohibition is therefore represented by engines with NOx emission performance well above the FTP emission standard.

References for Chapter 1

1. 2000 Wards Automotive Yearbook, page 59.

2. 2000 Wards Automotive Yearbook, page 59.

3. A copy of the Consent Decree between the United States and Volvo has been placed in the docket for this rulemaking, EPA Air Docket A-2001-30.. Though there are differences between the various Consent Decrees, with respect to the heavy-heavy service class emission limits and test procedures the various Consent Decrees contain the same requirements.

4. EPA Technical Memorandum "Summary of Model Year 2001 Heavy Duty Diesel Engine Certification Data", copy available in EPA Air Docket A-2001-25.

CHAPTER 2: TECHNOLOGIES NEEDED TO MEET 2004 STANDARDS

I. Projections of Technologies from 2000 FRM

In the 2000 FRM which affirmed the technical feasibility of the new HDDE 2004 NMHC+NOx emission standards (64 FR 58472, October 29, 1999), EPA presented a detailed discussion of the technologies we believed would enable a HDDE manufacturer to achieve the 2.5 g/bhp-hr NMHC+NOx standard. The following discussion will briefly summarize the technological feasibility discussion contained in the 2000 FRM, and the reader is refereed to the Regulatory Impact Analysis document of the previous rulemaking for a detailed discussion.[1]

A. Cooled Exhaust Gas Recirculation

EPA projected that cooled exhaust gas recirculation (cooled EGR) would be the principal technology used to reduce NOx emissions from the 1998 HDDE standard of 4.0 g/bhp-hr to the combined 2004 NMHC+NOx standard of 2.4 g/bhp-hr. Non-methane hydrocarbon emissions from modern on-highway HDDEs is relatively small, generally less than 0.5 g/bhp-hr, and it is expected that approximately a 50 percent reduction in NOx emissions will be necessary to achieve the 2004 NMHC+NOx standard. Cooled EGR lowers NOx emissions principally by replacing a portion of the fresh intake air oxygen with exhaust by-products and other inert gases, such as CO_2, water vapor, and N_2. These inert gases dilute the in-cylinder mixture and reduce the peak cylinder temperatures during the combustion process and thus reduce NOx formation. Thus, a cooled EGR system must be capable of routing exhaust gas from the exhaust system to the intake system, as well as cooling the exhaust during that process.

The cooled EGR technology projected by EPA to be used be engine manufacturers consists of several major hardware components, including an EGR cooler, EGR piping, and an electronically controlled EGR valve, as well as appropriate sensors to estimate the rate of EGR gas flow, such as a delta-pressure sensor.

One of the difficulties with using EGR in a turbocharged diesel engine is that for a large portion of the engines operating map (as represented by a full-load torque map), the intake manifold pressure is greater than the exhaust pressure, and therefore no EGR will flow into the intake manifold without some additional mechanism to change the pressure differential. In the RIA for the 2000 FRM we discussed several methods to overcome this pressure differential. However, for the Agency’s cost estimate in the 2000 FRM we assumed manufacturers would use a new turbocharger technology, variable geometry turbocharger (VGT), to assist in delivering and controlling EGR. A VGT, unlike the conventional fixed geometry turbochargers, provides some level of control over either the turbine vanes or the turbine exit geometry which provides a means to create additional back pressure in the exhaust system to drive EGR.

B. Improved Fuel Injection Systems

The Agency also predicted in the RIA of the 2000 FRM that manufacturers would use next-generation fuel injection technology in order to achieve the new 2004 NMHC+NOx standard. Relatively recent improvement in fuel injection systems for HDDEs, such as the common-rail system or advanced electronically controlled unit injectors, provide engineers with the ability to perform pilot injection, ramped injections, and post injections (in some cases multiple pilot and/or post injections). They can also provide engineers with complete control in some cases over injection pressure and duration. These systems provide important flexibilities for design engineers, including the ability for improved NOx and PM emissions performance.

C. Exhaust Aftertreatment Systems

The RIA for the 2000 FRM discussed several types of aftertreatment technologies which could be used with today's on-highway fuel sulfur levels, including diesel oxidation catalysts and lean NOx catalysts. In both cases, EPA did not predict that these technologies would be the prime technologies which would enable manufacturers to achieve the new 2004 NMHC+NOx standards, however, both technologies could provide modest emission reductions which could be combined with other technologies to achieve the necessary emission reductions.

Diesel oxidation catalysts (DOCs) are capable of oxidizing the soluble organic fraction (SOF) of diesel particulate matter as well as the hydrocarbons present in diesel exhaust. The SOF fraction of PM varies from engine to engine, but is typically on the order of 10 to 30 percent of the total particulate matter, which a DOC can essentially eliminate. As mentioned previously, NMHC from modern diesels is typically less than 0.5 g/bhp-hr, and a well functioning DOC can eliminate a significant portion of these hydrocarbons.

Lean NOx catalysts continue to offer limited NOx reduction capability when considered across the entire temperature operating range encountered by HD diesel engines, while peak reduction capabilities may approach 60 percent under limited operating range, overall reductions on the U.S. HD FTP continue to be modest, between 10 and 30 percent.

II. Current Manufacturer Projections

Engine manufacturers generally agree with us that cooled EGR is one of the principal technologies capable of achieving the 2004 emission standards. In the past several months, a number of engine manufacturers have announced they are pursuing cooled EGR technology as their principle means of complying with the 2004 standards.[2] In addition, at least one engine manufacturer has announced they are pursuing an alternative technology for complying with the 2004 HDDE standards which does not include the use of cooled EGR.[3]

III. Fuel Consumption Impacts

As is described in the next chapter, changes in fuel consumption are projected to be a significant component of the cost of compliance, in particular for medium-heavy and heavy-heavy duty diesel engines. We believe there are a number of reasons why some manufacturers are projecting a fuel consumption increase for their 2004 model year engines as compared to today's engines, as discussed below.

In the 2000 final rule RIA which affirmed the appropriateness of the 2004 standards, we discussed a number of technologies which manufacturers could use to meet the new NMHC+NOx standard. In that RIA, we discussed cooled EGR, improved fuel injection systems, advanced turbochargers, and next generation electronic controls. Of these technologies, EGR in particular has the potential to increase fuel consumption, if it is incorporated in isolation as an add-on component, and is not integrated successfully into a well designed system with the additional technologies. For on-highway HDDEs, a positive pressure differential exists between the exhaust manifold and the intake manifold over a large part of the engine map, which means that exhaust gases must be forced from the exhaust manifold to the intake manifold. This requires energy which can negatively impact efficiencies. However, we also discussed changes which can improve fuel efficiency, such as using better fuel systems which have a more favorable NOx-fuel economy trade-off, and the use of variable geometry turbochargers, which have the potential to provide efficiency gains in the air-handling system of the engine. For current engines, which do not incorporate these advanced NOx controls, manufacturers have relied heavily on timing retard to meet the applicable FTP emission standards. These current engines relying on injection timing for NOx control are now near the limits of the NOx reduction potential which can be achieved without excessive fuel economy penalties or adverse impacts on PM and durability.

The incorporation of all of these technologies (i.e., EGR, improved fuel systems, VGT, improved ECMs) into a HDDE is not a simple task, and it requires significant research and development. In general, we expect manufacturers to design their engines by first installing the hardware needed to achieve the new emission standards, and then to change EGR rates, VGT vane position, and/or fuel injection parameters (injection timing, injection rate, post/pre injection events) to optimize fuel consumption rates while maintaining NOx, HC, and PM control. This was discussed in both the 1997 final rule which established the 2004 standards, as well as the 2000 final rule which affirmed the new standards. During those rules, we estimated there would be no net long-term change in the fuel consumption performance of HDDEs, but there was a potential for higher fuel consumption rates in the short term. To the extent a manufacturer is unable to optimize its control system to meet the emission standards with the addition of the new hardware (e.g., EGR, fuel system improvements, and turbocharger improvements), they may be forced to rely more on fuel injection timing retard in the short term as their initial means of meeting the emission standards.

Based on the most recent information from engine manufacturers, including both public company announcements as well as the data presented in the next chapter, we see a wide range of estimated fuel economy impacts from companies. In the light-heavy market, we see some companies are predicting an improvement in fuel efficiency as compared to the current technology engines. In the medium-heavy and heavy-heavy markets, we see that while some companies are predicting no change in fuel economy for the 2004 model year, others are predicting decreased fuel efficiency, in some cases up to 5 percent. In large part, this range reflects the differing degrees to which manufacturers have invested in the research and development needed to optimize fuel consumption for their various products. We believe that a fully optimized EGR engine (or other advanced engines) will rely less on timing retard and will not experience any net fuel consumption increase compared to 4.0 g/bhp-hr NOx engines.

It is important to note that our analysis of fuel consumption impacts for heavy-heavy duty engines is affected by our setting the Upper Limit at 6.0 g/bhp-hr NMHC+NOx (which is discussed in more detail in the next chapter and in the preamble for this rulemaking). This 6.0 g/bhp-hr level is significantly greater than the current FTP NOx standard of 4.0g/bhp-hr, but it is representative of how current heavy-heavy duty engines operate in the field. This difference is largely due to how the engines are calibrated with respect to injection timing. There is also a corresponding difference in fuel consumption rates, with fuel consumption tending to be lower with 6.0 g/bhp-hr NMHC+NOx emissions. In the 1997 and 2000 rulemakings which established and affirmed the 2004 standard, we did not analyze the fuel economy impacts of reducing emissions from 6.0 g/bhp-hr NMHC+NOx to the 2004 standards. Thus we did not analyze in these previous rules the short-term or long-term fuel economy impacts for which manufactures are now providing us estimates. However, even for these heavy-heavy engines, at least one manufacturer has indicated that any increase in fuel consumption would be short-term in nature.[4]

References for Chapter 2

1. “Regulatory Impact Analysis Document: Control of Emissions of Air Pollution from Highway Heavy-duty Engines”, Chapter 3, EPA Publication # EPA-420-R-00-010, July 2000. Copy available in the Docket for this rule, EPA Air Docket A-2001-25.

2. “Documentation of Industry Press Releases Regarding Compliance with highway HD 2004 Standards in 2002", EPA Memorandum from William Charmley. Copy available in the docket for this rule, EPA Air Docket A-2001-25.

3. “Introducing Clean Power by Caterpillar”, Caterpillar brochure. Copy available in the docket for this rule, EPA Air Docket A-2001-25.

4. “Documentation of Industry Press Releases Regarding Compliance with highway HD 2004 Standards in 2002", EPA Memorandum from William Charmley. See specifically press release from Detroit Diesel Corporation. Copy available in the docket for this rule, EPA Air Docket A-2001-25.

CHAPTER 3: COMPLIANCE COSTS

This chapter describes our analysis of the costs of compliance. The analysis is based on our projections of actual measurable costs to manufacturers and operating costs for vehicle owners. It generally does not include analysis of engine pricing or vehicle purchaser perceptions that could affect purchase decisions.

I. Methodology

A. General Methodology

This chapter describes our analysis and projection of the costs of compliance for model year 2004, which are the primary inputs for determining NCPs. This analysis differs from the analyses for the model year 2004 standard-setting rulemakings in three basic ways:

(1) The goal of this analysis is to estimate manufacturer and operator costs during the first year of the new standards rather than to project the long-term societal costs.
(2) The baselines for calculation of compliance costs differ significantly.
(3) We now have more detailed information about costs identified in the earlier analysis, as well as cost categories not previously included.

The model year 2004 standard-setting analyses were based on a uniform emission control strategy for designing the different categories of engines to meet the standards. More specifically, we estimated the cost of developing an EGR system for a typical engine within a service class, and applied that per engine cost to all engines within the service class. However, for this NCP rulemaking, we considered the compliance costs on an engine model-by-engine model basis (or as close to that as possible based on the available data). We requested this information from several of the engine manufacturers for each engine model that they plan to produce for model year 2004. These data are described in Section II. We used these manufacturer estimates, along with other available information to estimate the average and 90th percentile compliance costs. In addition, it is necessary for this NCP analysis to focus solely on the compliance costs associated with the first year of production, while standard-setting analyses require a longer term view. This is most significant with respect to the costs associated with hardware, reliability (warranty, repairs, and associated costs), and fuel consumption. Manufacturers often make significant progress in reducing these costs with additional time. For example, in the recent final rule in which we affirmed the appropriateness of the 2004 NMHC+NOx standard, we suggested that in the short-term, average fuel consumption could increase by up to 1.0 percent, but in the long-term fuel consumption would remain either unchanged, or potentially decrease by up to 1.5 percent. However, we did not include the short-term fuel cost in the analysis. Similarly, the 2000 FRM analysis did not include an analysis of short-term warranty or repair costs. The only category in which we separately estimated short-term and long-term costs in the FRM was hardware cost category.

There is another important reason why the analysis for this specific NCP rulemaking is different from the analysis performed for the standards-setting rules. As is discussed later in this document, the engine designs currently produced and marketed under the Consent Decrees lead us to choose an Upper Limit value of 6.0 g/bhp-hr NMHC+NOx for the heavy-heavy duty service class, which fundamentally changes the cost analysis. The rationale for the heavy-heavy service class 6.0 g/bhp-hr NMHC+NOx upper limit is discussed in detail in Section III(C) of the Preamble. The penalty rate factors are based on the compliance costs associated with lowering the emissions from Upper Limit to the standard. So for heavy-heavy duty engines, the NCPs are based on the compliance costs associated with lowering the emissions from 6.0 g/bhp-hr NMHC+NOx to the 2004 standard of 2.5g/bhp-hr NMHC+NOx. This analysis was not performed in the standards-setting rules, and therefore the costs estimates in the standard-setting rule and this NCP rule are not comparable. For the standard-setting rules, we estimated the compliance costs associated with bringing an engine which meets the current NOx standard of 4.0 g/bhp-hr into compliance with the 2.5g/bhp-hr NMHC+NOx. This difference in baseline (6.0 vs. 4.0), has a significant impact on every cost category we have considered in this rulemaking, including the fixed, hardware, operating (including fuel consumption), and vehicle manufacturer costs.

Even for the other service classes, where we have established an Upper Limit based directly on the 4.0 g/bhp-hr NOx standard, the impact on engine designs of the alleged defeat device strategies used by a number of engine manufacturers over the past decade makes comparison between the standard-setting rule cost analysis and this analysis difficult. If such strategies had never been used, as was assumed in the standard-setting analyses, manufacturers would have optimized their current engines differently than their current products. Thus the two approaches for estimating compliance costs rely on different "baselines". A number of the manufacturers who submitted cost information on light-heavy and medium-heavy products are also companies who signed consent decrees with the government. The model year 2001 light-heavy and medium-heavy engines from Consent Decree companies must meet off-cycle emission performance which is equal to or comparable to the 4.0 g/bhp-hr NOx standard. However, in the past a number of these products were equipped with engine strategies whose use resulted in high NOx emission performance relative to the applicable emission standard. Manufacturers are continuing to spend research, development, and hardware money in order to address durability and other performance issues as a result of designing engines to meet the 2004 standards. It is likely that, in some cases, the issues that manufacturers are spending resources to address issues that are partially a result of the fact they can no longer use the problematic control strategies which were used in the past. For example, the combustion chambers in today's light- and medium-heavy duty engines have not been optimized as well as they would have been had manufacturers not used the problematic control strategies. This nonoptimization affects fixed costs, as well as fuel consumption and repair costs.

Finally, for this NCP rulemaking, we have received new information since the standard-setting FRMs. This included more detailed estimates of actual manufacturer costs, plus data on a few additional cost items which were not part of the standards-setting rulemaking analysis. Manufacturers are now able to provide more detailed cost information than they did during the earlier rulemakings because they are farther along the development path for compliance. They also now have a clearer understanding of the potential for additional costs. Specifically, we have included new cost items for vehicle manufacturer costs, post-warranty repairs, and revenue impacts. We did not have this information during the standard-setting rule. We have not evaluated whether post-warranty repairs and revenue impact costs would be significant over the longer term. However, we believe that these costs will occur during the first model year, and that it is appropriate to include them in this analysis. Based on submissions from manufacturers, it is clear that repair rates will decrease significantly within the first few years of production.

It is also important to point out that, in addition to the analytical differences described above, the resulting costs also differ because of the use of different baseline dollars. The rulemaking costs were estimated in terms of 1995 and 1999 dollars, while the costs in this analysis are expressed in terms of 2001 dollars. This is discussed in more detail in the following section.

B. Net Present Value of Costs

All costs are presented in 2001 dollars. Because the NCP is paid by the manufacturer in the model year that the engine is produced, we need to account for cost differences at the point of sale. All costs were converted to net present value (NPV) for calendar year 2004. Appendix B contains sample calculations showing how we dealt with the time value of money. Costs that occur prior to production (e.g., research and development) are adjusted upward by 7.0 percent per year. Costs that occur after production (e.g., fuel costs) are discounted by 7.0 percent per year. It is also important to remember that since all costs are presented in terms of constant 2001 dollars, the discount rate does not include an adjustment with respect to the rate of inflation.

Costs expressed in terms of 2000 or earlier dollars were adjusted upwards based on the Consumer Price Index (CPI) to be equivalent to 2001 dollars.[1] For example, the difference between a 1999 dollar and a 2001 dollar would be about six percent. We recognize that concerns have been raised about using the CPI to adjust costs for inflation. However, we are not aware of a better method for adjusting general costs for inflation. Also, given the relatively small number of years involved in the adjustments (generally three years or less), we believe that any errors introduced into the analysis by using the CPI would not be significant.

C. Costs Included

This section describes the cost categories that we included in our analysis. These costs include engine manufacturing costs, vehicle manufacturing costs, and operating costs. Engine manufacturer costs of control include variable costs (for incremental hardware, assembly, and associated markups), fixed costs (for tooling, R&D, etc.), and warranty costs. Vehicle manufacturers are also expected to incur some variable hardware costs, and may include some fixed costs. Owner costs include fuel costs, maintenance and repair costs, and costs associated with any time that the vehicle is down for repair.

We typically markup the variable hardware costs (or material costs) to the engine manufacturer at a rate of about 30 percent in our analyses. We do this to account for the engine manufacturer's overhead and profit that are associated with producing the new hardware. For this analysis, we asked engines manufacturers to include their markups in their estimates. Based on input from engine manufacturers, we believe that in some cases, *vehicle* manufacturers will need to make modifications to their vehicle designs to accommodate the new engines. Such changes could include larger cooling systems, or even larger engine compartments. We included these costs separately where applicable. We do not include any general vehicle manufacturer markup of engine manufacturer costs. We only included actual identifiable costs for the vehicle manufacturers, such as increased radiator size. It is appropriate to include a vehicle manufacturer markup for these costs, since these items are actually produced by the vehicle manufacturer to a large extent.

Fixed costs for R&D are incurred by the manufacturer several years before the standards take effect. Tooling costs are generally incurred at least one year ahead of initial production. Both kinds of fixed costs need to be increased for every year before the start of production to reflect the time value of the money invested in these expenditures. We used a seven percent annual rate for these adjustments, so costs incurred in years before 2004 are multiplied by 1.07^n (i.e., 1.07 raised to the n^{th} power). For example, fixed costs incurred in 2002 are converted to be equivalent to costs incurred in 2004 by multiplying them by 1.07^2. The fixed cost estimates reported by the manufacturers should account for this by specifying the costs in terms of NPV for calendar year 2004. In general, we amortized this total pre-production cost at seven percent interest over a five-year period during which the manufacturer would be able to recoup the fixed costs. We did not include certification costs because manufacturers would incur these costs whether or not they used NCPs. Appendix B shows a sample calculation of how we accounted for the time value of fixed costs.

Manufacturers would generally be expected to incur additional warranty costs due to the addition of new components. For this analysis, the relevant costs would be the total warranty cost to the engine manufacturer for the new emission control hardware related to the first model year of production. Typically, this would cover the costs of repairs that are needed within the first two calendar years of vehicle life (the typical warranty period for heavy duty engines).

These new systems can incur other additional maintenance costs that are projected to be incurred at regular mileage intervals throughout the vehicle life, or at rebuild. There can also be additional unscheduled repairs to the new hardware. Considered from the point of purchase (i.e., 2004), these repair and maintenance costs are future costs and thus are discounted in this analysis. For both warranty repairs and post-warranty repairs, there are also real costs incurred by the vehicle owners for demurrage (i.e., the time during which the vehicle is out of service).

Manufacturers have indicated that they expect some of the new compliant engines to have different fuel consumption rates than the noncompliant engines. We projected the changes in lifetime brake-specific fuel consumption that will occur for vehicles produced in the first model year of production.

Both the maintenance and fuel costs are dependent on the number of miles projected to be driven by the vehicles. For this analysis, we used the same projected mileage accumulation rates that we have used in previous rulemakings. These projections are shown in Appendix A, along with projection of vehicle survival fractions that are based on projected scrappage rates. These projections are described in a 2001 EPA Technical Report.[2] We use the survival fractions to weight the mileage rates to estimate the number of miles driven by typical vehicles within each service class. These estimates do not distinguish between miles driven before rebuild and miles driven after rebuild. These newer mileage estimates are slightly different from the estimates used in the 2004 FRM.

D. Upper Limit Engine

The upper limit is an important aspect of the NCP regulations not only because it establishes an emission level above which no engine can be certified, but it is also a critical component of the cost analysis used to develop the NCP factors. The regulations specify that the relevant NCP costs for determining the COC_{50} and the COC_{90} factors are the difference between an engine at the upper limit and one that meets the new standards (see 40 CFR 86.1113-87). A full discussion of the rationale for the Upper Limit for each service class is contained in the Preamble.

Upper Limit for Heavy-Heavy Duty

As described in the Preamble for this rule, an NMHC+NOx value of 6.0 g/bhp-hr is the appropriate upper limit for heavy-heavy duty engines.

Upper Limit for Light-Heavy Duty, Medium-Heavy Duty, and Urban Buses

As described in the Preamble for this rule, an NMHC+NOx value of 4.5 g/bhp-hr is the appropriate upper limit for light-heavy duty, medium-heavy duty, and urban buses.

E. Use of Optional Standard

The 2004 standard has two forms. The first form is 2.4 g/bhp-hr NOx+NMHC for combined emissions, with no constraint specific to either NOx or NMHC. The second form is an optional 2.5 g/bhp-hr NOx+NMHC for engine families that meet a 0.5 g/bhp-hr NMHC cap. As described above, we expect that all manufacturers will meet 0.5 g/bhp-hr NMHC cap, whether they use NCPs or not. It is also our understanding that all of the compliance costs that we received were for compliance with the second form. Thus, we have based our analysis on the second form of the standard.

We are applying the same NCP parameters (for UL, COC_{50}, COC_{90}, MC_{50}, and F) for all engines, without regard to form of the standard to which the manufacturer certifies. The effect of this would be that the X value for engines certified to the first form (without the NMHC constraint) would be 0.1 g/bhp-hr lower than the values listed in Chapter 4. This would have the effect of raising the penalty level slightly for any given NOx+NMHC compliance level.

II. Manufacturer Cost Data

Prior to the NPRM, we requested from several of the engine manufacturers detailed cost estimates for each compliant engine model that they plan to produce for model year 2004. We requested that all costs be presented in 2001 dollars and adjusted to their net present value for the year 2004. We also requested that manufacturers include only emission-related costs. The companies that we contacted are listed in a memorandum to the docket for this rulemaking.[3] That memorandum also includes more details about our request. Table 3-1 shows the sample data table that we sent to the manufacturers.

Table 3-1
Example of Cost Data provided for One Engine Configuration

Item	Baseline Engine	2004 Engine
Family Name or Identifier		
Engine Configuration Description		
Technology Description		
Value of Fixed Costs -NPV 2004 - research & development - tooling - others	N/A	
2004 Hardware Cost-NPV 2004	N/A	
2004 Warranty Cost - NPV 2004		
Maintenance/Operating Cost - NPV 2004	N/A	
Brake-Specific Fuel Consumption (lb/bhp-hr)		
U.S. Sales		
Vehicle packaging costs	N/A	

Prior to the proposal, we received responses from most of the manufacturers that we contacted, representing the majority of the current U.S. heavy duty diesel engine market. However, all of the data that we received were identified as confidential business information (CBI). Therefore, we are not including details of the submissions in this document. Instead we are presenting only the summary shown in Tables 3-2 through 3-4. This summary format was approved by all of the manufacturers that provided CBI data for this rulemaking. However, one manufacturer requested that their estimates of operating costs not be included in these summary tables, therefore those numbers do not appear in the tables.

Some of the manufacturers that submitted cost information prior to the proposal submitted revised estimates during the comment period for this rulemaking. The summary tables below show these more recent data. Some of the other manufacturers reaffirmed their earlier submissions in their public comments. We contacted those manufacturers who did not revise or reaffirm their cost estimates during the comment period, and confirmed with them that their earlier submissions remained valid. During our contacts with manufacturers, we clarified their methods for projecting the NPV of their fixed costs. We also requested documents showing internal cost projections (e.g., briefing documents for senior management) from each heavy-heavy duty engine manufacturer that provided cost data.[4] However, not all of the manufacturers provided such documents. Nevertheless, the internal documents that we did receive were consistent with the cost projections that manufacturers provided to us as part of this rulemaking.

With the exception of fixed costs, the manufacturer data presented in these tables were provided to EPA on a consistent basis for model year 2004. However, in some cases, our follow-up conversation indicated that the fixed costs needed to be adjusted and amortized to fit the format described above and in Appendix B. Total fixed costs for each manufacturer were divided by the manufacturers' actual reported sales for model year 2000 to determine per engine fixed costs. The fixed cost estimates in Tables 3-2 through 3-4 are shown using the same NPV methodology. These data are rank-ordered from the highest value to the lowest value from right to left independently for each cost category (e.g., heavy-heavy fixed costs). Thus, a column of data does not represent any specific engine manufacturer's estimates. We have done this in order to maintain the confidential nature of the cost data manufacturers submitted to EPA. It is also important to note that though we requested data from manufacturers on all heavy duty service classes, we received no data specific to urban buses.

Table 3-2
Engine Manufacturer Cost Submissions for Light-Heavy Service Class

Cost Category	Manufacturer Data - per Engine Costs		
Amortized Fixed Costs ($/engine)	unknown at this time	$397	$536
Hardware Costs, includes engine manufacture markup	$530	$793	$1,512
Warranty	no change or better than today's product	unknown at this time	$115
Operating Costs (excluding fuel economy impacts)	unknown at this time	unknown at this time	estimate not releasable*
Fuel Consumption Impact	unknown at this time	2 % improvement	2 % improvement
Vehicle Manufacturing Cost ($/engine) includes vehicle manufacture markup	$0	unknown at this time	$130

* Detailed inputs provided on change in oil change intervals, demurrage (i.e., down time), and repairs outside the warranty period, but manufacturer did not allow cost estimate to be placed in the public record.

Table 3-3
Engine Manufacturer Cost Submissions for Medium-Heavy Service Class

Cost Category	Manufacturer Data - per Engine Costs				
Amortized Fixed Costs ($/engine)	no estimate provided	$291	$495	$856	$988
Hardware Costs, includes engine manufacturer markup	$223	$433	$750	$793	$1,500
Warranty	unknown at this time	$0	$0	$10	$765
Operating Costs (excluding fuel economy impacts)	$0	unknown at this time	unknown at this time	$1,672	estimate not releasable*
Lost Revenue due to increased engine weight	no estimate provided	no estimate provided	no estimate provided	no estimate provided	$196
Fuel Consumption Impact	no change	unknown at this time	3% worse	4% worse	5% worse
Vehicle Manufacturing Cost ($/engine) includes vehicle manufacture markup	$0	unknown at this time	unknown at this time	$100	$155

* Detailed inputs provided on change in oil change intervals, demurrage (i.e., down time), repairs outside the warranty period, and revenue impacts from increased engine weight, but manufacturer did not allow cost estimate to be placed in the public record.

Table 3-4
Engine Manufacturer Cost Submissions for Heavy-Heavy Service Class

Cost Category	Manufacturer Data - per Engine Costs				
Amortized Fixed Costs ($/engine)	$395	$404	$506	$940	$1,982
Hardware Costs, includes engine manufacture markup	$1,100	$1,298	$1,559	$2,520	$2,899
Warranty	$0	$23	$188	$840	$1,680
Operating Costs: (excluding fuel economy impacts)	$0	$0	unknown at this time	$429	estimate not releasable*
Lost Revenue due to increased engine weight	no estimate provided	no estimate provided	no estimate provided	no estimate provided	$871
Fuel Consumption Impact	0 to 1 percent better	2 percent worse	3 percent worse	3 to 5 percent worse	3 to 5 percent worse
Vehicle Manufacturing Cost ($/engine), includes vehicle manufacture markup	$150	$195	$250 to $350	$408	$500

* Detailed inputs provided on change in oil change intervals, demurrage (i.e., down time), repairs outside the warranty period, and revenue impacts from increased engine weight, but manufacturer did not allow cost estimate to be placed in the public record.

III. Analysis of Costs

Our estimated average compliance costs (COC_{50}) and 90th percentile costs (COC_{90}) are shown in Tables 3-5 through 3-7. These estimates are based on the data provided by manufacturers, independent cost analyses, and the Agency's technical judgement. The derivation of these estimates is described in detail below. The estimated 90th percentile cost is conceptually equivalent to high-mileage vehicles from a high-cost manufacturer, although not necessarily the highest cost manufacturer. This concept is described in detail in the COC_{90} section below. Derivation of these parameters for urban buses is described separately at the end of this section.

Table 3-5
Light-Heavy COC50 and COC90 Estimates
(Net Present Value to 2004 in 2001 Dollars)

	COC_{50}	**COC_{90}**
Per Engine Fixed Cost	$500	$700
Hardware Cost	$810	$1,500
Warranty Cost	$30	$120
Operating Costs: Scheduled Maintenance	$0	$0
Operating Costs: Post-Warranty Repairs	$30	$190
Operating Costs: Demurrage	$20	$70
Fuel Cost ($) @ $1.34 / gal[a]	($280 savings)	$0
Operating Costs: Revenue Impact	$0	$0
Vehicle Manufacturing Costs	$130	$130
Total	**$1,240**	**$2,710**

[a] As discussed in Section III(A) of this Chapter under the heading "Fuel Costs", fuel costs were estimated using a price of $1.29/gallon for 2004 and 2005, and $1.34/gallon for 2006 and beyond.

Table 3-6
Medium-Heavy COC_{50} and COC_{90} Estimates
(Net Present Value to 2004 in 2001 Dollars)

	COC_{50}	COC_{90}
Per Engine Fixed Cost	$540	$700
Hardware Cost	$810	$1,200
Warranty Cost	$160	$360
Operating Costs: Scheduled Maintenance	$90	$150
Operating Costs Post-Warranty Repairs	$170	$510
Operating Costs: Demurrage	$100	$250
Fuel Cost ($) @ $1.34 / gal[a]	$780	$1,560
Operating Costs: Revenue Impact	$20	$50
Vehicle Manufacturing Costs	$70	$150
Total	**$2,740**	**$4,930**

[a] As discussed in Section III(A) of this Chapter under the heading "Fuel Costs", fuel costs were estimated using a price of $1.29/gallon for 2004 and 2005, and $1.34/gallon for 2006 and beyond.

Table 3-7
Heavy-Heavy COC_{50} and COC_{90} Estimates
(Net Present Value to 2004 in 2001 Dollars)

	COC_{50}	**COC_{90}**
Per Engine Fixed Cost	$610	$900
Hardware Cost	$1,890	$2,340
Warranty Cost	$380	$700
Operating Costs: Scheduled Maintenance	$460	$800
Operating Costs: Post-Warranty Repairs	$370	$940
Operating Costs: Demurrage	$220	$470
Fuel Cost ($) @ $1.34 / gal[(a)]	$2,500	$5,930
Operating Costs: Revenue Impact	$80	$170
Vehicle Manufacturing Costs	$300	$500
Total	**$6,810**	**$12,210**

[(a)] As discussed in Section III(A) of this Chapter under the heading “Fuel Costs”, fuel costs were estimated using a price of $1.29/gallon for 2004 and 2005, and $1.34/gallon for 2006 and beyond.

A. COC_{50}

Fixed Costs and Hardware Costs

Average per-engine fixed costs were calculated as the sales-weighted average of the manufacturer data shown in Tables 3-2 through 3-4. The average hardware costs were calculated as the sales-weighted average of the engine hardware costs provided by manufacturers. Sales-weighting was done using the independent sales information provided by manufacturers.[5]

We adjusted the hardware costs for heavy-heavy duty engines to account for a reduction in costs expected from experience gained from the pull-ahead production that is required under the Consent Decrees. In our recent rulemakings, we have estimated that hardware costs drop by 20 percent after two years of production. Since nearly all of the heavy-heavy duty engines currently sold in the U.S. are manufactured by companies that are required to pull-ahead production by 15 months, we believe that hardware costs for model year 2004 will be lower than the costs manufacturers gave to us. Based on the estimate that hardware costs should drop by 20 percent after two years of production, we believe that hardware costs should drop by at least 10 percent after 15 months of production. Therefore, we have adjusted the manufacturers hardware costs for heavy-heavy duty engines down by 10 percent to more accurately reflect expected actual hardware costs for model year 2004.

Warranty Costs

The estimates of expected incremental warranty costs provided by manufacturers covered a wide range. In some cases, they provided us with detailed analyses. In the proposal, we sales-weighted the manufacturers information to estimate the average warranty costs in the same manner as we did for fixed and hardware costs. However, we now believe that this is not the most appropriate methodology for medium- and heavy-heavy duty engines. As shown in Tables 3-3 through 3-4, the manufacturers' estimates vary greatly. To some degree these differences are the result of manufacturers using different approaches to estimating these costs. Some manufacturers are much more conservative in projecting these costs than others. Since the manufacturers' projections are not equivalent, we do not believe that averaging them together would be the most appropriate approach. In the standard-setting rulemakings, we estimated that long-term marginal warranty costs would be equal to 10 percent of the new hardware costs. For this analysis, where we are looking at costs for model year 2004, we believe that it would be more appropriate to use 20 percent of the hardware costs. This reflects the reality that short-term warranty costs for a new product would be expected to be significantly higher than long-term warranty costs for a mature product. The resulting estimated warranty costs are in the middles of the ranges, and are significantly less than the most conservative estimate. These estimates are closer to the median of the manufacturer estimates than to the sales-weighted average.

For light-heavy duty engines, we used the proposed approach of sales-weighting the manufacturers information to estimate the average warranty costs. The range of estimates provided by the manufacturers was not as large for light-heavy duty engines, and showed no evidence of being conservative. In fact, the manufacturer estimates were significantly less than 20 percent of the hardware costs. The lower estimates are reasonable since the number of miles covered during the warranty period for a light-heavy duty engine is much less than for the other service classes.

The estimated average warranty costs were divided by estimated repair costs of $300, $400 and $500 per repair for light-, medium- and heavy-heavy duty, respectively, to estimate the repair rates in Table 3-8. The average repair costs are based on confidential information provided by manufacturers. These estimates for medium- and heavy-heavy duty are less than used in the draft analysis because of new manufacturer information. The resulting estimated repair rates during the warranty periods are used to estimate repair costs after the warranty period, which is included as part of the maintenance costs described in the next sub-section titled "Operating Costs: Post-Warranty Repairs, Demurrage, and Scheduled Maintenance Costs".

Operating Costs: Post-Warranty Repairs, Demurrage, and Scheduled Maintenance Costs

We asked manufacturers to provide us with estimates of the incremental maintenance costs that would be associated with their new engines. However, not all of the manufacturers provided estimates. Some only provided qualitative descriptions, while others provided no estimates. Also, some included maintenance costs with demurrage, while others did not. After reviewing these different estimates, it became clear that they were not consistent, and that we needed to estimate maintenance and demurrage costs separately.

Based on the confidential submissions from the manufacturers (that is, the detail behind the manufacturers cost information in Tables 3-2 through 3-4) , we estimate that for the first model year, the incremental rate of repairs (repairs per vehicle-mile) after the warranty period would be one-half of the rate within the warranty period. This is a reasonable expectation because during the warranty period when repairs are performed, manufacturers often will incorporate additional, preemptive repairs which the engine manufacturer has learned is needed, but did not cause a failure on the vehicle/engine. We also estimate that the typical warranty period would be two years.[6] Given the projected mileage accumulation rates listed in Appendix A, this would mean that the number of miles covered within the warranty period would be about 55,000 miles for light-heavy duty, 70,000 miles for medium-heavy duty, and 215,000 miles for heavy-heavy duty. The post-warranty period is estimated to be the difference between these mileages and the typical lifetime mileages from Appendix A (209,000, 262,000 and 767,000 miles) The estimated costs associated with incremental post-warranty repairs are shown in Table 3-9.

For both warranty and post-warranty repairs, we estimated the cost associated with demurrage (i.e., the cost of the vehicle being out of service), assuming that a repair frequently removes the vehicle for service for some time. To determine how long a vehicle would be out of service for each repair, we considered the per repair cost estimate discussed under the Warranty Costs sub-section above, in which we estimated the average per-repair cost to be $300, $400 and $500 per repair for light-, medium- and heavy-heavy duty, respectively. Based on these costs, which would include labor and parts, we believe that a typical repair will be completed within one day. While a few repairs may take more than one day, many others may be completed in less than one day, or even during other scheduled maintenance. Thus, our estimated demurrage costs are equal to the approximate cost of renting a vehicle for one day[7], plus $50.00 for administrative costs (including the labor cost associated with picking up and returning the vehicle), but not including a rental mileage charge.[a] Mileage rates charged by rental fleets are typically roughly equivalent to the price of the vehicle divided by the number of miles expected for its lifetime (e.g., $50,000 / 300,000 miles = 17 cents per mile for a typical medium-heavy duty vehicle). Thus, the cost of mileage to a fleet operator would be comparable whether the miles were driven in a rental vehicle or in its own vehicle. The demurrage cost does not include costs associated with failures that occur on the road, and which cause the vehicle to cease being operational until repaired. What little data we received from manufacturers indicates that this type of catastrophic failure should not be common The estimated costs of demurrage are $90, $140, and $170 per repair for LHDE, MHDE, and HHDE, respectively. The NPV values shown in Tables 3-2 through 3-4 are the total combined values for the demurrage costs for warranty repairs and for post-warranty repairs.

We recognize that manufacturers typically markup replacement parts. While we do not believe that it is necessarily appropriate to make additional profit from the in-use failure of emission-related parts, we do believe that there are legitimate overhead costs that should be included in the cost of the parts. We estimate that parts will comprise 60 percent of the warranty costs and should be marked-up by 30 percent for post-warranty repairs. This means that post-warranty repairs would cost 1.18 times as much as warranty repairs.[b] Given the expected sensitivity of customers to the potential for failure of new technology, we believe that manufacturers will be reluctant to markup emission-related replacement parts any more than this.

In the 2000 FRM, we projected that additional maintenance costs would be incurred for medium- and heavy-heavy duty engines when they are rebuilt to ensure proper functioning of the EGR systems. No similar costs were estimated for light-heavy duty engines because of the lower mileage accumulation rates and the much lower rate of engine rebuilding. We are projecting that EGR equipped engines will require replacement of the EGR valve and cleaning of the EGR

(a) Note: the estimate of the equivalent out-of-service cost in the draft analysis included an additional $30 per day for insurance that we now believe is not relevant for most truck operations.

(b) [60% × 130%] + [40% × 100%] = 118%

cooler at rebuild. We estimate that the incremental cost for the EGR valve replacement will be $100 for MHDE and $150 for HHDE. Based on manufacturer comments, we believe that different cooling methods will be used for different engines, depending on engine design and on operator preference. We are projecting that one-half of the cooler cleaning will involve core-swap at a cost of $400 for HHDE and $150 for MHDE, and the other half will be cleaned by the operator at a cost of $80 (equivalent to approximately one hour of labor). The estimated costs for core-swaps of the coolers are equivalent to the hardware costs to a manufacturer for the cooler during the original manufacture of the engine, plus markup. Our cost estimates are based on the information provided by manufacturers. We believe that this estimate properly accounts for labor costs to remove and reinstall the cooler during rebuilding, cleaning and pressure-testing costs, shipping and handling of the old cooler and cleaned coolers, and the cost for replacing damaged coolers than cannot be cleaned. We are projecting the rebuild costs to occur at mileages equal to the length of the engine's useful life (185,000 and 435,000 miles). The NPV of these costs (adjusted to 2001 dollars) are shown in Table 3-10. It is important to note that at least one manufacturer has indicated that it will not use cooled-EGR. Therefore, we are projecting that one-third of all medium- and heavy-heavy duty engines will have no incremental costs during rebuild. The resulting average rebuild costs are $260 for HHDE, and $140 for MHDE. The net present value of these costs would be about $200 for HHDE, and $90 for MHDE.

Some manufacturers indicated that they will recommend shorter oil change intervals for their EGR-equipped engines to address problems with soot loading and acidification. However, other manufacturers projected that there will be no changes in oil change intervals, or did not provide specific comments regarding oil change intervals. Based on this information, we are projecting that this effect will be negligible for the average light- and medium-heavy duty engine over its lifetime, but for heavy-heavy duty, we are projecting that the typical engine will require about 2 additional oil changes over its lifetime. This is equivalent to an engine requiring an oil change every 32,000 miles instead of every 35,000 miles. We estimate the cost of an oil change to be $180.[c] The net present value of the two additional oil changes would be about $260 per engine.

(c) Our estimate is based on estimates provided by one engine manufacturer, one national fleet operator, and one independent truck service center. These estimates were $120, $176, and $195 per oil change (including labor, oil, and filters).

Table 3-8
Estimated Average Warranty Costs and Repair Rates

	Average Warranty Cost per Engine	Warranty Miles	Cost per Repair	Incremental Repairs per Vehicle Within Warranty Period
Light Heavy	$30	55,000	$300	0.10
Medium Heavy	$160	70,000	$400	0.40
Heavy Heavy	$380	215,000	$500	0.76

Table 3-9
Estimated Average Post-Warranty Repair Costs

	Post-Warranty Miles	Incremental Repairs per Vehicle After Warranty Period	Cost per Repair	NPV of Repairs
Light Heavy	154,000	0.14	$350	$30
Medium Heavy	192,000	0.55	$470	$170
Heavy Heavy	552,000	0.98	$590	$370

Table 3-10
Estimated NPV Average Scheduled Maintenance Costs

	Increased Oil Change	EGR Maintenance at Rebuild	Average Scheduled Maintenance Cost per Engine
Light Heavy	$0	$0	$0
Medium Heavy	$0	$90	$90
Heavy Heavy	$260	$200	$460

Fuel Costs

We estimated fuel penalties using VMT (vehicle-miles traveled) patterns listed in Appendix A and the estimates of expected percent changes in fuel consumption listed in Table 3-11. These estimates of percent change in fuel consumption rates fall within the range of estimates provided by manufacturers for this rulemaking. We developed these estimates using the sales-weighted averages manufacturers projections, which were consistent with their internal estimates that manufacturers are using for planning purposes. However, since internal cost projections may be somewhat conservative for internal cost projections, we also considered the manufacturers' public projections of fuel consumption impacts, especially for heavy-heavy duty engines. In general, the public projections of fuel consumption impacts reflected lower fuel consumption rates than the manufacturers' submissions to EPA, often more than one percent better.[8] Expecting lower fuel consumption rates is reasonable since market demands will force manufacturers to continue to reduce fuel consumption rates to the maximum extent possible over the next year or two. We are estimating that actual fuel consumption impacts will be between the manufacturers' internal projections and their public statements for model year 2004 to balance any tendency for the estimates to be either conservative or optimistic. Our estimate of the percent change in fuel consumption rates for heavy-heavy duty engines is about one-half of one percent lower than the sales-weighted average of the manufacturer projection that were submitted to EPA, which is higher than the manufacturers' public projections. Given the lower demand for fuel consumption improvements for other engines, a smaller adjustment was made to the manufacturer projection for medium-heavy duty, and no adjustment was made for light-heavy duty.

We calculated the NPV of these impacts using a fuel price of $1.29 per gallon for calendar years 2004 and 2005, and a fuel price of $1.34 per gallon for later calendar years to account for the introduction of lower sulfur fuel. The $1.29 price represents the five-year average retail price of on-highway diesel fuel for 1997 through 2001 (EIA estimate)[9] adjusted to be equivalent to 2001 dollars, plus 44 cents for federal and state tax. Appendix A contains a detailed description of the estimated mileage accumulation rates that we used in our analysis.

As shown in Figure 3-1, diesel fuel prices have been highly variable, even when adjusted for inflation. We are using a five-year average because we believe that it is a better estimate of future fuel prices than a single-year average. In addition, it probably also better approximates how purchasers will make purchase decisions, considering the economic significance of changes in fuel consumption rates.

Figure 3-1

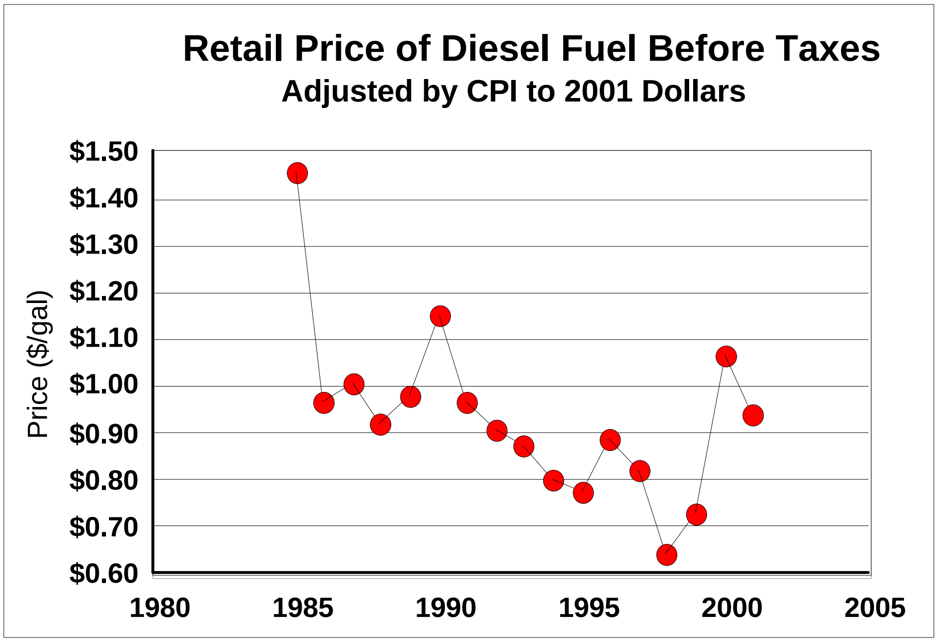


Table 3-11
Estimated Average Lifetime Mileage and Fuel Consumption Change

	VMT for Average Vehicle	Average Change in Fuel Consumption	2004 NPV of Fuel Impact
Light Heavy	209,000	-2.0%	($280 savings)
Medium Heavy	262,000	+2.5%	$780
Heavy Heavy	767,000	+2.0%	$2,500

Operating Costs: Revenue Impacts

Some engine manufacturers suggested that there could be some increase in engine/vehicle weight as a result of the new standards which could have a small impact on revenue for trucks operating at their weight limit. Other manufacturers, however, did not. Manufacturer estimates of the increase in weight ranged from zero to 100 pounds. Based on these inputs, we are estimating that the average medium- and heavy-heavy duty vehicle will weigh 40 and 50 pounds more than current vehicles, respectively.

We are estimating revenue impacts for this increase in weight based on the operation of liquid tanker trucks, which are often weight limited. According to the U.S. Census Bureau [10], operation of tanker trucks comprises approximately 7 percent of all medium- and heavy-heavy duty truck operation. We also estimate that tanker revenue is approximately 8 cents per ton-mile.[11] While we recognize that these trucks are not always weight limited, we also recognize that trucks other than tankers can be weight limited. We believe that these two factors largely offset one another. It is also important to note that, while we requested comment on how to best estimate revenue impacts, we received no new data.

Assuming that freight revenue is 8 cents per ton-mile, and that these trucks operate at their weight limit 7 percent of the time, 50 additional pounds could cost a heavy-heavy duty truck operator about $80 (NPV) over a typical vehicle life of 760,000 miles. For medium-heavy duty, we estimate that the revenue impact of 40 additional pounds would be $20 (NPV) over a typical vehicle life of 262,000 miles.

Vehicle Manufacturing Costs

Engine manufacturers estimated increased vehicle manufacturing costs of up to $500 for vehicles changes such as bigger fans and radiators. We estimated the average incremental vehicle cost to be equal to the sales-weighted average of the engine manufacturer's estimates. which are $130 for light-heavy duty, $70 for medium-heavy duty, and $300 for heavy-heavy duty. These estimates include a vehicle manufacturer markup.

B. COC_{90}

The estimated 90th percentile cost is conceptually equivalent to high-mileage vehicles from a high-cost manufacturer. However, we did not base this on the highest mileage vehicle and the highest cost vehicles, since that would result in the 99th percentile costs. Given the relative market shares of the various engine manufacturers, as well as the relative importance of fuel costs and engine manufacturer costs, we determined that it would be appropriate to use the 70th percentile mileage accumulation rates to calculate changes in fuel consumption and other operating costs which are proportional to mileage, such as post-warranty repair rates and revenue impacts. Assuming no co-dependence of the distributions, we would need to target the 67th percentile of engine manufacturer costs (and other manufacturer specific parameters, such as percent change in fuel consumption) to result in precisely 10 percent of the model year 2004 fleet having both mileage accumulations and engine costs at least this high.[d] Given concerns about protecting confidential business information, as well as the fact that we did not receive information for every manufacturer, we cannot describe our COC_{90} analysis in terms of actual cost data from a specific manufacturer. Instead, we used in our COC_{90} analysis representative numbers from the higher cost manufacturer(s), as described below.

We have attempted to estimate costs representative of the 67th percentile engine manufacturer costs for fixed costs, hardware costs, warranty costs and vehicle manufacturer costs. Similarly, we attempted to estimate rates representative of the 67th percentile engine for post-warranty repair rates (repairs per mile, not the repair costs), decreased oil change intervals, revenue impact due to weight increase, and change in fuel consumption rate (percent change). For most inputs, we used values representative of the highest two or three manufacturer values. However, for light-heavy duty, where we often had only two manufacturer estimates for a given cost category, we sometimes used the single highest cost. When considered together, our estimated COC_{90} costs are less than the highest compliance costs reported by the highest cost manufacturer.

Fixed Costs and Hardware Costs

We estimated the COC_{90} fixed costs and hardware costs from the same manufacturer estimates used to calculate the COC_{50} estimates (including the downward adjustment of the hardware costs by 10 percent to reflect manufacturer production experience prior to 2004). In general, we estimated the COC_{90} cost to be between the two highest estimates. However, the estimated fixed cost for heavy-heavy engines is between the second and third highest manufacturer estimates because the manufacturer data with the highest fixed cost estimate represents a relatively small fraction of the heavy-heavy duty market.

(d) Assuming no co-dependence between manufacturing costs and mileage accumulation rates, 90th percentile costs occur when the product of (100%-manufacturing cost percentile) and (100%-mileage percentile) is equal to 10%. For example, for 70th percentile mileage rates, the manufacturing cost percentile that would correspond to ten percent of the fleet would be the 67th percentile; (100% - 67%) X (100%-70%) = 0.33 X 0.30 = 0.10 =10%. Thus, 1/3 of the model year's production will have manufacturing costs at least as high as the 67th percentile, and 30 percent of those engines (or 10 percent of the total) will have lifetime mileage accumulation at least as high as the 70th percentile value. Similarly, for 80th percentile mileage rates, the manufacturing cost percentile that would correspond to ten percent of the fleet would be the 50th percentile; (100% - 50%) X (100%-80%) = 0.50 X 0.20 = 0.10 =10%. However, based on the cost information provided by manufacturers, the ten percent of the fleet captured by this 50/80 analysis would have lower costs than the ten percent of the fleet captured by the 67/70 analysis used here.

Warranty Costs

Warranty costs depend on several different factors, such as hardware cost, technology design, past corporate warranty practices, etc. Thus, it is reasonable to expect that COC_{90} warranty costs would be higher than the average costs. For the medium- and heavy-heavy duty analysis, we estimated COC_{90} warranty repair rates to be 50 percent higher than the average repair rates, so that warranty costs would be estimated as 30 percent of the COC_{90} hardware costs, as opposed to the 20 percent estimate for COC_{50}. These costs are shown in Table 3-12. Consistent with the COC_{50} warranty analysis, we used the manufacturer costs to estimate the light-heavy duty COC_{90} warranty costs. We estimate that the COC_{90} warranty cost for light-heavy duty will be equal to the highest warranty cost estimated by a manufacturer.

Operating Costs: Post-Warranty Repairs, Demurrage, and Scheduled Maintenance Costs

We estimated 90th percentile post-warranty repair and demurrage costs in the same manner as the average costs. However, we based the repair frequency (repairs per mile) on this COC_{90} warranty cost estimate, and on the 70th percentile mileage rates. For scheduled maintenance, we estimated COC_{90} costs in the same manner as COC_{50} costs. We estimated no increase in the number of rebuilds. However, since the COC_{90} engine is projected to be an EGR engine, rebuild costs would include EGR valve replacement and EGR cooler cleaning/core-swap for all engines (i.e., half of the COC_{90} engines would have the coolers cleaned, while the other half would have a core-swap). The NPV of these rebuild estimated costs is $150 for MHDE and $300 for HHDE. Post-warranty repair and maintenance costs are shown in Tables 3-13 and 3-14.

We estimate that, for the heavy-heavy COC_{90} engine, there will be 4 more oil changes over the life of the vehicle (for 70th percentile mileage rates). This is equivalent to an engine requiring an oil change every 31,000 miles instead of every 35,000 miles. We estimated the cost of an oil change to be $180. The net present value of this would be about $500 per engine. We are projecting that this effect will be negligible for the average light- and medium-heavy duty engines.

Table 3-12
Estimated Warranty Costs and Repair Rates for COC_{90}

	Warranty Cost per Engine	Warranty Miles	Cost per Repair	Incremental Repairs per Vehicle Within Warranty Period
Light Heavy	$120	55,000	$300	0.40
Medium Heavy	$360	70,000	$400	0.90
Heavy Heavy	$700	215,000	$500	1.40

Table 3-13
Estimated Post-Warranty Repair Costs for COC_{90}

	Post-Warranty Miles	Incremental Repairs per Vehicle After Warranty Period	Cost per Repair	NPV of Repair Costs
Light Heavy	225,000	0.82	$350	$70
Medium Heavy	273,000	1.76	$470	$250
Heavy Heavy	785,000	2.56	$590	$470

Table 3-14
Estimated Scheduled Maintenance Costs for COC_{90}

	Increased Oil Change	EGR Maintenance at Rebuild	Average Scheduled Maintenance Cost per Engine
Light Heavy	$0	$0	$0
Medium Heavy	$0	$150	$150
Heavy Heavy	$500	$300	$800

Fuel Costs

We estimated 90th percentile fuel costs in the same manner as the average rates. However, we based the percentile change on the COC_{90} engines (e.g., a HHDDE with a 3.5% fuel consumption increase), and used the 70th percentile mileage rates. The estimated impacts are shown in Table 3-15. This analysis is shown in Appendix A.

The estimates of percent change in fuel consumption rates fall within the range of estimates provided by manufacturers for this rulemaking. As we did for the COC_{50} analysis, we also considered the manufacturers' public projections of fuel consumption impacts. Our estimate of the percent change in fuel consumption rates for medium- and heavy-heavy duty engines is near the low end of the range of estimates of the high cost manufacturers. For light-heavy-duty engines, the two manufacturers that provided estimates for fuel consumption impacts each projected a two percent improvement in fuel consumption. This would represent a lifetime savings of a few hundred dollars for the average light-heavy-duty vehicle. However, if different configurations and driving patterns are considered, we believe that there would likely not be significant fuel savings for the COC_{90} vehicles.

Table 3-15
Estimated Lifetime Mileage and Fuel Consumption Change for COC_{90}

	VMT for Average Vehicle	Change in Fuel Consumption	2004 NPV of Fuel Impact
Light Heavy	280,000	No Change	$0
Medium Heavy	343,000	+4%	$1,560
Heavy Heavy	1,000,000	+3.5%	$5,390

Operating Costs: Revenue Impacts

Based on manufacturer inputs, we are estimating that the COC_{90} medium- and heavy-heavy duty vehicle will weigh 70 and 80 pounds more than current vehicles, respectively. Assuming that freight revenue is 8 cents per ton-mile, and that these trucks operate at their weight limit 7 percent of the time, 50 additional pounds could cost a heavy-heavy duty truck operator about $170 (NPV) over a vehicle life of 1,000,000 miles. For medium-heavy duty, we estimate that the revenue impact of 40 additional pounds would be $50 (NPV) over a vehicle life of 343,000 miles.

Vehicle Manufacturing Costs

We estimated the COC_{90} vehicle cost as approximately the highest estimate provided by engine manufacturers.

C. MC_{50} and F

MC_{50} and F are two parameters used in the existing regulations in the calculation of the value X (see 40 CFR 86.1113-87 (a)(4)). X is the compliance level(g/bhp-hr) above the standard where the penalty equals $COC_{50.}$ This section describes the derivation of MC_{50} and F for light-, medium-, and heavy-heavy duty engines. The values for urban buses are described in a later section.

Estimated value of MC_{50}

MC_{50} is the marginal cost of compliance for the average vehicle, expressed in terms of dollars per gram of NMHC+NOx emission controlled. In concept, it would be based on the difference in total compliance costs for an engine that had emissions equal to the standard (i.e., 2.5 g/bhp-hr) and an engine that had emissions slightly above the standard. For example, if we had an estimate of the total cost of compliance for a typical engine with emissions equal to 2.6 g/bhp-hr, then we would calculate MC_{50} as the difference between that cost and the average divided by the difference in emissions (0.1 g/bhp-hr). However, in the case of this rulemaking, we do not have such detailed information. Therefore, we have estimated MC_{50} based on the estimated costs of those control strategies that we believe will be used by manufacturers to achieve marginal NOx or NMHC control near the 2.5 g/bhp-hr standard.

We are aware of studies that investigated the effect of injection timing retard on NOx emissions and fuel consumption for HDDEs with emission performance on the order of 2.5 g/bhp-hr NOx.[12,13] These studies showed marginal fuel consumption changes of 0.2 to 0.8 percent increase in fuel consumption for each 0.1 g/bhp-hr of NOx reduction. Similar effects have been observed with changes in EGR rate.[13] Another study looked at other diesel engine types, and found marginal fuel consumption changes of 0.3 to 0.6 percent increase in fuel consumption for each 0.1 g/bhp-hr of NOx reduction.[14] For this analysis, we are estimating that the average marginal cost of achieving the last 0.1 g/bhp-hr of NOx reduction for light-, medium-, and heavy-heavy duty is equivalent to a 0.45 percent increase in fuel consumption, or $60, $140, and $560, respectively, based on the data cited above.

We are also aware that at least one manufacturer is considering using a diesel oxidation catalyst (DOC) to reduce NMHC emissions from light-heavy duty engines. Based on information provided by light-heavy duty engine manufacturers, we have estimated cost effectiveness of using DOCs to reduce hydrocarbons. In a 1998 submission to EPA, the

Manufacturers of Emission Control Associations (MECA) estimated a range of costs for a DOC for a light-heavy duty engine to be between \$230 and \$500 (1998 dollars), using typical engine displacement, engine family production volumes, and industry wide production volumes for the light-heavy duty diesel engine market.[15] Given the current emission rates for light-heavy duty engines, we project that a DOC would reduce hydrocarbons by about 0.2 g/bhp-hr. Based on this information and the recent manufacturer data, we estimate that the marginal cost of compliance would be \$200 per 0.1 g/bhp-hr of NMHC+NOx reduced (in 2001 dollars). We are using this value to estimate MC_{50} for light-heavy duty engines since this cost is higher than the cost of a 0.45 percent increase in fuel consumption for light-heavy duty engines.

Based on the preceding analysis, we estimate MC_{50} for light-, medium-, and heavy-heavy duty to be \$2000, \$1600, and \$5600, respectively. It is useful to compare these values to the minimum values of MC_{50} (i.e., the average cost of compliance (COC_{50}) divided by the difference between the standard and the upper limit). MC_{50} would equal the minimum value if all of the emission controls were equally cost effective. Given our estimates of COC_{50}, and our upper limits, the minimum values for MC_{50} are \$620, \$1370, and \$1950 for light-, medium-, and heavy-heavy duty vehicles.

Estimated value of F

The parameter F is defined in the existing regulations as a value from 1.1 to 1.3 that describes the ratio of the 90th percentile marginal cost (MC_{90}) to MC_{50}. Given that the MC_{50} for medium- and heavy-heavy duty is estimated to be equivalent to a 0.45 percent increase in fuel consumption per 0.1 g/bhp-hr, we considered the F values that would be associated with the observed experimental range of fuel consumption impacts described above.[7,8] The high end of the range of 0.8 percent increase per 0.1 g/bhp-hr would be equivalent to an F value of 1.8, which is outside of the range allowed by the existing regulations. An F value of 1.3 would be equivalent to a 0.59 percent increase per 0.1 g/bhp-hr. We believe that the true value of MC_{90} is likely to be between these two estimates, and therefore are setting F equal to 1.3.

For light-heavy duty, a catalyst at the upper range of the MECA cost (\$545 in 2001 dollars) that would reduce NMHC emissions by 0.2 g/bhp-hr would result in an F value of 1.36. Thus, we are setting F at the maximum level of 1.3 for light-heavy duty.

D. Urban Buses

We did not receive any cost information specific to urban buses. Therefore, we are basing our cost estimates on the information provided for heavy-heavy duty engines because an urban bus is a sub-category of the heavy-heavy service class. We estimate that the per-engine fixed costs, hardware costs, and vehicle costs will be the same for buses as for other heavy-heavy duty engines. We estimate that there would be no revenue impact. Our estimated warranty and maintenance costs were derived using the same per-mile costs as for other heavy-heavy duty engines. However, we estimated no cost associated with demurrage. We estimated MC_{50} and F in the same manner as we did for the heavy-heavy duty service class, but used the bus-specific fuel consumption costs.

Table 3-16
Estimate of Warranty Costs, Post-Warranty Repair Costs, and Maintenance Costs (Oil Changes for Urban Buses

	COC_{50} Estimates		COC_{90} Estimates	
	Urban Bus	**Other HHDV**	**Urban Bus**	**Other HHDV**
Warranty Period Miles	89,000	215,000	89,000	215,000
Warranty Cost	$160	$380	$290	$700
Post-Warranty Miles	501,000	552,000	511,000	785,000
Post-Warranty Repair Cost	$340	$370	$610	$940
Total Life Miles	590,000	767,000	600,000	1,000,000
Oil Cost	$210	$270	$300	$500

The fuel costs were calculated using the bus-specific mileage estimates in Appendix A, and our estimates of the bus-specific fuel consumption rate impacts shown in Table 3-17. These estimates (0.5 percent for COC_{50} and 2.0 percent for COC_{90}) are 1.5 percent lower than the corresponding rates estimated for other heavy-heavy duty engines. This difference is intended to reflect the effect of setting the upper limit at 4.5 instead of 6.0, while keeping the hardware for bus engines the same as for other heavy-heavy duty engines. For the proposal, we estimated that this difference in upper limits could be approximated by reducing the heavy-heavy fuel consumption penalty by 2.0 percent. However, the net adjustment must also reflect differences in in-use operation and the lesser degree to which manufacturers will optimize urban bus fuel consumption. These differences probably would have resulted in a difference of about 0.5 percent if these engines had the same upper limit. Thus, we are estimating that the fuel consumption penalty for urban buses will be 1.5 percent less than it will be for other heavy-heavy duty engines.

Table 3-17
Estimated Lifetime Mileage and Fuel Consumption Change

	VMT	Change in Fuel Consumption	2004 NPV of Fuel Impact
COC_{50}	590,000	0.5%	$420
COC_{90}	600,000	2.0%	$1,720

Table 3-18
Urban Bus COC_{50} and COC_{90} Estimates
(Net Present Value to 2004 in 2001 Dollars)

	COC_{50}	COC_{90}
Per Engine Fixed Cost	$610	$900
Hardware Cost	$1,890	$2,340
Warranty Cost	$160	$290
Operating Costs: Scheduled Maintenance	$210	$300
Operating Costs: Post-Warranty Repairs	$340	$610
Operating Costs: Demurrage	$0	$0
Fuel Cost	$420	$1,720
Operating Costs: Revenue Impact	$0	$0
Vehicle packaging costs	$300	$500
Total	**$3,930**	**$6,660**

References for Chapter 3

1. U.S. Department of Labor, Bureau of Labor Statistics, CPI Inflation Calculator, http://data.bls.gov/cgi-bin/cpicalc.pl.

2. "Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Mileage Accumulation Rates and Projected Vehicle Counts for Use in MOBILE6", EPA420-R-01-047, September 2001.

3. "Collection of Compliance Cost Estimates for the Purpose of Establishing NCPs for the 2004 Heavy duty Diesel NMHC+NOx Emission Standard", Roberts French, EPA Memorandum, copy available in the docket for this rulemaking.

4. "Internal Company Documents Submitted to EPA for NCP Rulemaking", Charles Moulis, EPA Memorandum, copy available in the docket for this rulemaking.

5. "Data Received from Heavy Duty Diesel Engine Companies regarding 2001 Medium-Heavy and Heavy-Heavy Diesel Engine Sales", William Charmley, EPA Memorandum, copy available in the docket for this rulemaking.

6. "Heavy-duty Diesel Engine Warranty Information", Charles Moulis, EPA Memorandum, copy available in the docket for this rulemaking.

7. Estimated rental prices are based on prices published at www.ryder.com, a copy of the published prices has been placed in the docket for this rulemaking.

8. "Documentation of recent Heavy-duty Diesel Engine Industry Press Releases, Trade Journal Articles, and other Material Regarding Fuel Economy Performance", William Charmley, EPA Memorandum, copy available in the docket for this rulemaking.

9. U.S. Department of Energy, Energy Information Administration, Petroleum Marketing Monthly, Table 17, April 2002.

10. "1997 Economic Census: Vehicle Inventory and Use Survey", U.S. Census Bureau, EC97TV-US, October 1999.

11. "Infrastructure Requirements for an Expanded Fuel Ethanol Industry", Chapter 4, Downstream Alternatives Inc., January 15, 2002.

12. "Cooled EGR - A Key Technology for Future Efficient HD Diesels", P. Zelenka et. al. Society of Automotive Engineers Technical Paper # 980190, February 1998.

13. “Gaseous Emissions from a Caterpillar 3176 (with EGR) Using a Matrix of Diesel Fuels (Phase 2)”, Southwest Research Institute, September 1999. Copy available in the docket for this rulemaking.

14. "European Programme on Emissions, Fuels and Engine Technologies (EPEFE) - Heavy Duty Diesel Study, M. Signer, et al., Society of Automotive Engineers Technical Paper #961074, May, 1996.

15. “Report on Agreed-Upon Procedures”, Manufacturers of Emission Control Associations, December 17, 1998, Available in EPA Air Docket A-98-32, Docket Item # II-D-09.

CHAPTER 4: REGULATORY PARAMETERS FOR NCPs

I. NCP Equations and Parameters

EPA's existing regulations for calculating NCPs are contained in 40 CFR Part 86 Subpart L. NCP schedules can be calculated from those same equations using the Upper Limit, COC_{50}, COC_{90}, MC_{50}, and F values from the previous chapter, and a standard level (S) of 2.5 g/bhp-hr NMHC+NOx. The values for X are calculated using these values and the following equation from Subpart L:

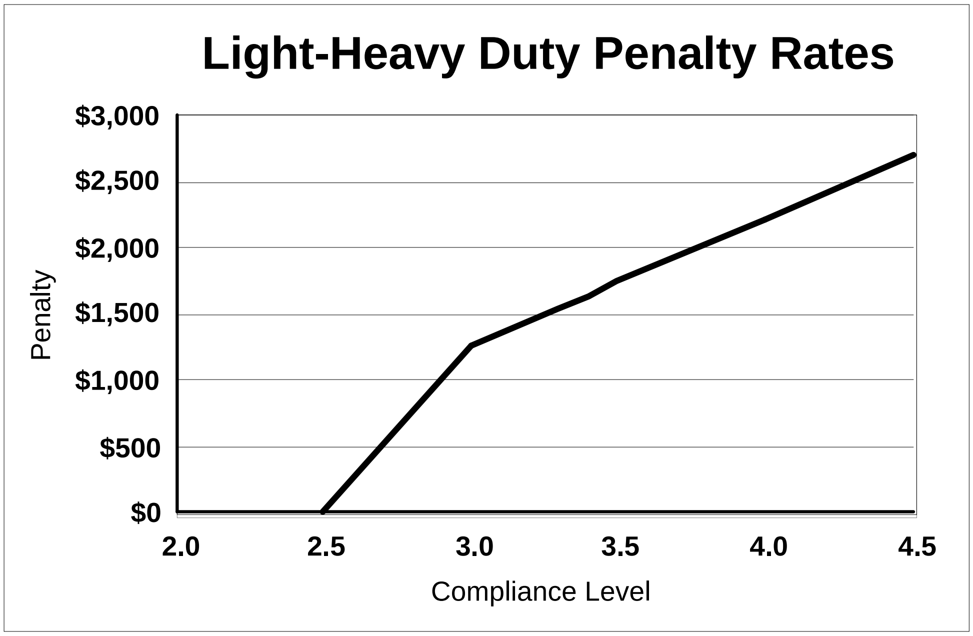
$$X = (COC_{50} / F / MC_{50}) + S$$

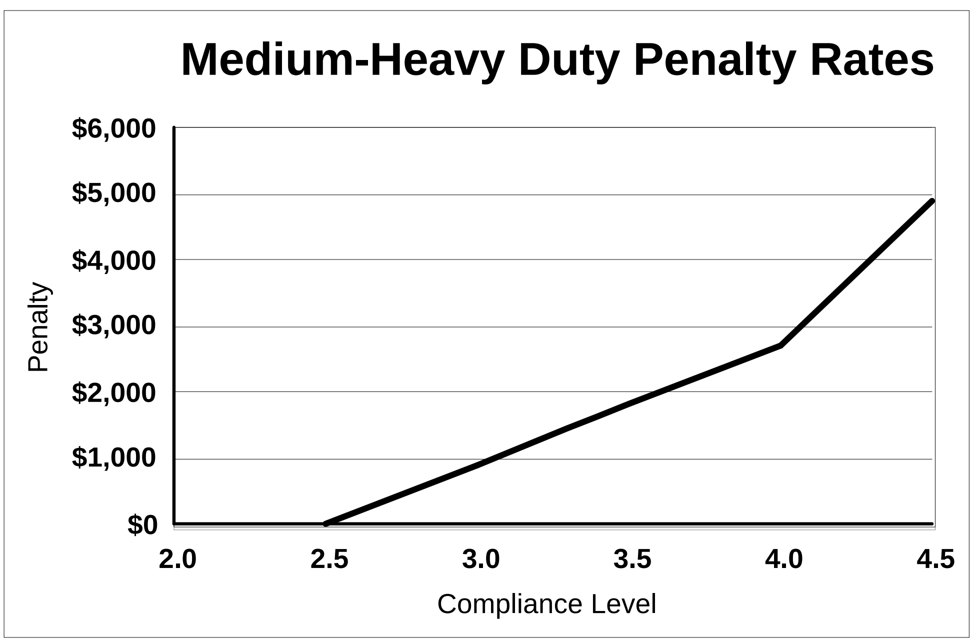
The purpose of this equation is to achieve a penalty curve in which the slope for engines with compliance levels near the standard is equal to the 90th percentile marginal cost of compliance (MC_{90} equals MC_{50} times F).

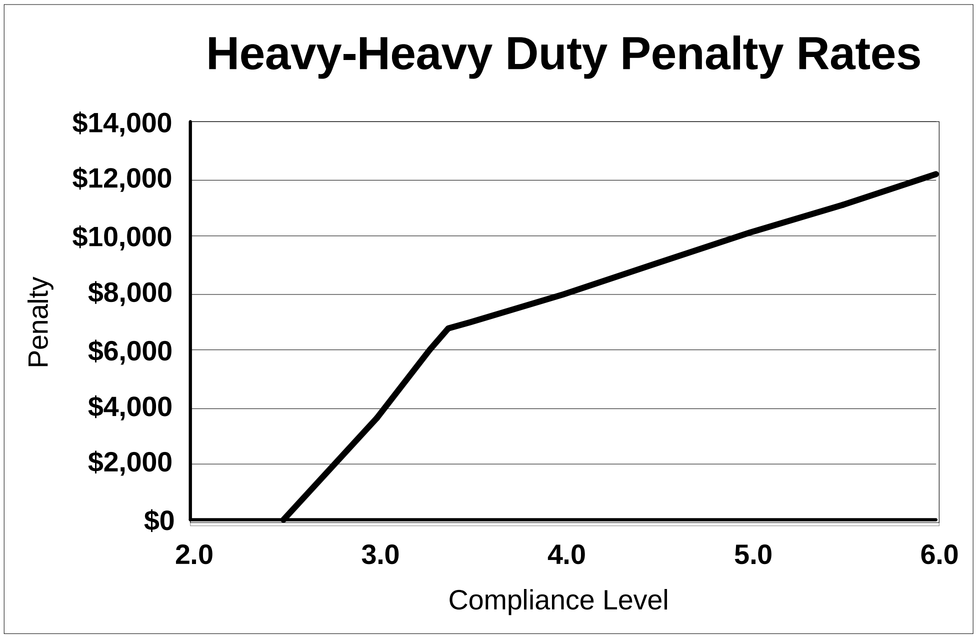
Table 4-1
Parameters for NCP Equations

	Light-Heavy	Medium-Heavy	Heavy-Heavy	Urban Bus
COC_{50}	$1,240	$2,740	$6,810	$3,930
COC_{90}	$2,710	$4,930	$12,210	$6,660
MC_{50}	$2,000 per g/bhp-hr	$1,400 per g/bhp-hr	$5,600 per g/bhp-hr	$3,800 per g/bhp-hr
F	1.3	1.3	1.3	1.3
UL	4.5	4.5	6.0	4.5
X	3.0	4.0	3.4	3.3

When the factors listed in Table 4-1 are input into the existing NCP equations specified in 40 CFR 86.1113(a)(1) and (2), for year n=1 (that is, the first year the penalties are used, thus the annual adjustment factor is equal to 1), the resulting penalty vs. compliance level for each service class are shown in Figures 4-1 through 4-4.


Light-Heavy Duty Penalty Rates
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Penalty
2.0
2.5
3.0
3.5
4.0
4.5
Compliance Level


Medium-Heavy Duty Penalty Rates
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
Penalty
2.0
2.5
3.0
3.5
4.0
4.5
Compliance Level


Heavy-Heavy Duty Penalty Rates
$14,000
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$0
Penalty
2.0
3.0
4.0
5.0
6.0
Compliance Level


Urban Bus Penalty Rates
$7
$6
$5
$4
$3
$2
$1
$0
Penalty
Thousands
2.0
2.5
3.0
3.5
4.0
4.5
Compliance Level

II. Refund for Engineering and Development Costs

Section 1113-87(h) of the existing regulations specify provisions under which a manufacturer that pays NCPs can recover some of the amount it has paid, provided it certifies a conforming replacement for the engines which used the NCPs. The maximum amount that can be recovered is limited to 90 percent of the portion of the penalty which EPA determines to be related to engineering and development. Thus, it is necessary for EPA to establish in each NCP rule a factor for each service class ($F_{E\&D}$) which define the fractions of the NCP which is considered to be related to engineering and development. We are setting these factors equal to the ratio of the projected average fixed costs per engine divided by the COC_{50} for each class. The factors are listed in Table 4-2.

Table 4-2
Engineering and Development Refund Factors

Light-Heavy Duty Engines	0.403
Medium-Heavy Duty Engines	0.197
Heavy-Heavy Duty Engines	0.090
Urban Bus Engines	0.155

APPENDIX A: FUEL CALCULATIONS

This appendix lists the inputs used to project fuel costs. It also details an analysis of the net present value (NPV) of changes in fuel consumption. The projected fuel cost changes are shown for one percent changes in fuel consumption rates. These resulting NPV projections are directly proportional to the percent change in fuel consumption, whether it is positive or negative.

The first table lists the inputs used for the analysis. The second table shows the weighted average VMT rates and the project change in annual fuel cost for a typical vehicle. The weighted average VMT rates are the products of the "Annual VMT" and "Survival Fraction" entries from Table A-1. Thus, Table A-2 represents the fleet average of all 2004 model year vehicles within a given class (e.g., light-heavy duty diesel vehicles). With the exception of urban buses, Table A-3 represents individual 2004 model year vehicles that remain in service for 19 years. Our data indicate that 70 percent of these vehicles remain in service for 19 years or less. Thus, we project that 30 percent of model year 2004 heavy duty vehicles would have fuel cost impacts equal to or greater than those listed at the bottom of Table A-3 for each one percent change in their fuel consumption rates. For urban buses Table A-3 represents individual 2004 model year buses that remain in service for 17 years.

Table A-1
Inputs Used for Fuel Consumption Analysis

	Light HDDV	Medium HDDV	Heavy HDDV	NPV Discount Rate = 0.07
Base fuel economy, mi/gallon	14	8.0	6.0	Cost of Diesel Fuel = 1.34/gallon (Includes 5 cents/gal for low sulfur after 2005)
Percent increase in fuel consumption	1.0%	1.0%	1.0%	

Annual VMT and Fraction of Vehicle Remaining in the Fleet vs. Vehicle Age

	Light HDDV		Medium HDDV		Heavy HDDV		Urban Bus	
Vehicle Age	Annual VMT	Survival Fraction	Annual VMT	Survival Fraction	Annual VMT	Survival Fraction	Annual VMT	Survival Fraction
1	28,951	1.000	36493	1.000	113,208	1.000	45171	1.000
2	26,479	1.000	33203	1.000	102,211	1.000	43731	1.000
3	24,226	0.932	30221	0.935	92,288	0.935	42337	1.000
4	22,173	0.870	27519	0.875	83,332	0.875	40987	1.000
5	20,301	0.811	25069	0.818	75,250	0.818	39681	1.000
6	18,593	0.756	22849	0.765	67,954	0.765	38416	1.000
7	17,035	0.705	20836	0.715	61,369	0.716	37191	1.000
8	15,613	0.657	19012	0.669	55,424	0.670	36005	1.000
9	14,314	0.613	17359	0.626	50,059	0.626	34857	1.000
10	13,128	0.572	15861	0.585	45,214	0.586	33746	0.999
11	12,043	0.533	14502	0.547	40,840	0.548	32670	0.996
12	11,052	0.497	13271	0.512	36,892	0.513	31629	0.989
13	10,146	0.464	12155	0.478	33,327	0.479	30620	0.970
14	9,317	0.432	11145	0.447	30,107	0.448	29644	0.925
15	8,558	0.403	10228	0.418	27,200	0.419	28699	0.832
16	7,864	0.376	9397	0.391	24,575	0.392	27784	0.662
17	7,227	0.351	8644	0.366	22,204	0.367	26898	0.413
18	6,645	0.327	7962	0.342	20,063	0.343	26041	0.197
19	6,111	0.305	7342	0.32	18,129	0.321	25211	0.161
20	5,622	0.284	6782	0.299	16,382	0.300	24407	0.132
21	5,173	0.265	6274	0.28	14,804	0.281	23629	0.108
22	4,762	0.247	5814	0.262	13,379	0.263	22875	0.089
23	4,384	0.231	5396	0.245	12,091	0.246	22146	0.072
24	4,038	0.215	5017	0.229	10928	0.230	21440	0.059
25	3,720	0.207	4674	0.218	9877	0.220	20757	0.065
26	3,427	0.194	4363	0.204	8928	0.207	20095	0.033
27	3,159	0.177	4082	0.179	8069	0.179	19454	0.033
28	2,913	0.167	3826	0.179	7294	0.179	18834	0.033
29	2,686	0.153	3595	0.165	6595	0.165	18234	0.016
30	2,477	0.119	3385	0.151	5962	0.152	17652	0.016

Table A-2
Average Per Vehicle Cost From 1% Increase in Fuel Consumption

	Light HDDV		Medium HDDV		Heavy HDDV		Urban Bus	
Age	**VMT**	**Fuel Penalty**	**VMT**	**Fuel Penalty**	**VMT**	**Fuel Penalty**	**VMT**	**Fuel Penalty**
1	28,951	$27	36,493	$59	113,208	$243	45,171	$97
2	26,479	$24	33,203	$53	102,211	$219	43,731	$94
3	22,579	$22	28,257	$47	86,289	$192	42,337	$94
4	19,291	$18	24,079	$40	72,916	$163	40,987	$91
5	16,464	$16	20,506	$34	61,555	$137	39,681	$88
6	14,056	$13	17,479	$29	51,985	$116	38,416	$86
7	12,010	$11	14,898	$25	43,940	$98	37,191	$83
8	10,258	$10	12,719	$21	37,134	$83	35,995	$80
9	8,774	$8	10,867	$18	31,337	$70	34,847	$78
10	7,509	$7	9,279	$16	26,495	$59	33,707	$75
11	6,419	$6	7,933	$13	22,380	$50	32,547	$73
12	5,493	$5	6,795	$11	18,926	$42	31,273	$70
13	4,708	$4	5,810	$10	15,964	$36	29,692	$66
14	4,025	$4	4,982	$8	13,488	$30	27,427	$61
15	3,449	$3	4,275	$7	11,397	$25	23,876	$53
16	2,957	$3	3,674	$6	9,633	$21	18,381	$41
17	2,537	$2	3,164	$5	8,149	$18	11,115	$25
18	2,173	$2	2,723	$5	6,882	$15	5,136	$11
19	1,864	$2	2,349	$4	5,819	$13	4,070	$9
20	1,597	$2	2,028	$3	4,915	$11	3,228	$7
21	1,371	$1	1,757	$3	4,160	$9	2,559	$6
22	1,176	$1	1,523	$3	3,519	$8	2,028	$5
23	1,013	$1	1,322	$2	2,974	$7	1,605	$4
24	868	$1	1,149	$2	2,513	$6	1,275	$3
25	770	$1	1,019	$2	2,173	$5	1,353	$3
26	665	$1	890	$1	1,848	$4	655	$1
27	559	$1	731	$1	1,444	$3	634	$1
28	486	$0	685	$1	1,306	$3	614	$1
29	411	$0	593	$1	1,088	$2	297	$1
30	295	$0	511	$1	906	$2	288	$1
Total	209,205	$198	261,692	$433	766,554	$1,691	590,116	$1,309
NPV		$143		$313		$1,246		$844

Table A-3
High Case per Vehicle Cost From 1% Increase in Fuel Consumption
For 30 Percent Remaining in Fleet

	Light HDDV		Medium HDDV		Heavy HDDV		Urban Bus	
Age	**VMT**	**Fuel Penalty**	**VMT**	**Fuel Penalty**	**VMT**	**Fuel Penalty**	**VMT**	**Fuel Penalty**
1	28,951	$27	36,493	$59	113,208	$243	45171	$97
2	26,479	$24	33,203	$53	102,211	$219	43731	$94
3	24,226	$23	30,221	$51	92,288	$206	42337	$94
4	22,173	$21	27,519	$46	83,332	$186	40987	$91
5	20,301	$19	25,069	$42	75,250	$168	39681	$88
6	18,593	$18	22,849	$38	67,954	$152	38416	$86
7	17,035	$16	20,836	$35	61,369	$137	37191	$83
8	15,613	$15	19,012	$32	55,424	$124	36005	$80
9	14,314	$14	17,359	$29	50,059	$112	34857	$78
10	13,128	$13	15,861	$27	45,214	$101	33746	$75
11	12,043	$12	14,502	$24	40,840	$91	32670	$73
12	11,052	$11	13,271	$22	36,892	$82	31629	$71
13	10,146	$10	12,155	$20	33,327	$74	30620	$68
14	9,317	$9	11,145	$19	30,107	$67	29644	$66
15	8,558	$8	10,228	$17	27,200	$61	28699	$64
16	7,864	$8	9,397	$16	24,575	$55	27784	$62
17	7,227	$7	8,644	$14	22,204	$50	26898	$60
18	6,645	$6	7,962	$13	20,063	$45	0	$0
19	6,111	$6	7,342	$12	18,129	$40	0	$0
20	0	$0	0	$0	0	$0	0	$0
Total	279,776	$265	343,068	$569	999,646	$2,211	600,066	$1,311
NPV		$180		$389		$1,536		$858

APPENDIX B: SAMPLE COST CALCULATIONS

This appendix shows sample calculations for some of the cost components used in the analysis. It shows how fixed costs were adjusted to constant 2001 dollars, and how they were amortized. It also shows how per-mile fuel cost impacts were calculated. The last table shows the annual cost stream from the owner's perspective. Manufacturer costs are expressed as retail price equivalents, without regard to the extent to which the manufacturers actually pass the costs on to the customers.

Sample Calculation of NPV Fixed Costs from
Annual Fixed Costs from a Manufacturer

Calendar Year That Money Is Spent	Research Spending[1]	Tooling Costs[1]	Total Fixed Costs for Calendar Year	Value of Dollars for Reported Costs[2]	CPI Adjustment to 2001 Dollars	Total Annual Fixed Cost in 2001 Dollars[2]	NPV of Annual Fixed Costs[3]
1998	$5,000,000		$5,000,000	1998	1.087	$5,435,000	$8,156,469
1999	$5,000,000		$5,000,000	1999	1.063	$5,315,000	$7,454,562
2000	$10,000,000		$10,000,000	2000	1.029	$10,290,000	$13,488,091
2001	$10,000,000		$10,000,000	2001	1.000	$10,000,000	$12,250,430
2002	$10,000,000	$1,000,000	$11,000,000	2001	1.000	$11,000,000	$12,593,900
2003	$10,000,000	$3,000,000	$13,000,000	2001	1.000	$13,000,000	$13,910,000
* Costs for 2001 - 2003 are projected costs, costs for 1998 - 2000 are actual costs						Total NPV =	$67,853,453

1 Costs for 2001 - 2003 are projected costs, costs for 1998 - 2000 are actual costs.

2 Actual costs were generally reported in terms of actual dollars spent in a calendar year without adjusting for inflation. These costs were adjusted upwards based on the Consumer Price Index to be equivalent to 2001 dollars. Projected costs are generally reported in terms of current year dollars.

3 The net present value of these costs were calculated by multiplying the cost (in 2001 dollars) by 1.07^n, where n = (2004 - the year of the cost).

Sample Amortization of Fixed Costs[1] for a Manufacturer

Total Fixed Costs (2004 NPV)	$67,853,453
Recovery Period (years)	5
Recovery Rate	7%
Amortized Cost	$16,548,826
Sales per Year	30000
Amortized Cost per Engine	$552

1 Total NPV fixed costs are amortized to be recovered as equal annual payments at the end of calendar years 2004, 2005, 2006, 2007, and 2008 with a return of 7% of the outstanding balance at the beginning of the year.

Sample Calculation of Per Mile Fuel Costs

Fuel Economy (miles/gal)		6.0
Fuel Consumption (gal/mile)	=1/6.0	0.167
Increase in Fuel Consumption (%)		1.0%
Increase in Fuel Consumption (gal/mi)	= (0.167) x (0.010)	0.00167
Increased Fuel Cost ($/1000 miles)	= (0.00167)x($1.338)x(1000)	$2.24

Sample Annual Costs for a Model Year 2004 Vehicle[1]

	Amortized Fixed	**Engine Manufacturer Hardware**	**Manufacturer Warranty Cost**	**Vehicle Manufacturer Cost**	**Fuel Cost**	**Other Operating**
2004	$552	$1,800	$100	$100	$708	$118
2005			$100		$639	$106
2006					$557	$224
2007					$471	$189
2008					$398	$274 [2]
2009					$336	$135
2010					$284	$114
2011					$240	$96
2012					$202	$81
2013					$171	$69
2014					$145	$58
2015					$122	$49
2016					$103	$41
2017					$87	$35
2018					$74	$30
2019					$62	$25
2020					$53	$21
2021					$44	$18
2022					$38	$15
2023					$32	$13
2024					$27	$11
2025					$23	$9
2026					$19	$8
2027					$16	$7
2028					$14	$6
2029					$12	$5
2030					$9	$4
2031					$8	$3
2032					$7	$3
2033					$6	$2
NPV (2004)	$552	$1,800	$193	$100	$3,615	$1,232

1 Costs are presented on a fleet wide average basis. As shown in Appendix A, estimates of annual miles traveled account for the number of miles traveled by vehicles in the fleet and the fraction of vehicles remaining in the fleet.

2 Includes cost for rebuild at end of useful life.